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FIRE CONTROL TECHNICIAN

1 & C

NAVY TRAINING COURSES

NAVPERS 10162 VOL. 3 COPY NO.

FIRE CONTROL TECHNICIAN
1 & C

VOL. III

Prepared by

U.S BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

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PREFACE

This book is written as an aid in preparing Fire Control Technicians 2 and 1 for promotion to the rates of Fire Control Technician 1 and Chief Fire Control Technician.

Because of the extensive qualifications required by Fire Control Technician 1 and Chief Fire Control Technician (see appendix II), it was found advisable to divide the study material into several volumes. This book covers the general aspects of fire-control radar. The other volume or volumes are concerned primarily with surface, anti-aircraft, torpedo and underwater fire control.

Since men in the Fire Control Technician rates are becoming more and more a group of system or equipment experts, it is the present purpose to include in the Navy Training Courses more of the basic material which is applicable to all types of systems rather than to emphasize a single system. Whenever a specific system is described in the text, it is done mainly for the purpose of applying certain basic fundamentals or to show the applications of theoretical materials.

As one of the Navy Training Courses, this book represents the joint endeavor of the Training Publications Section in the Bureau of Naval Personnel and those naval establishments especially cognizant of the technical aspects of fire control. Special credit is given to the Fire Control Technician School, Class B, Washington D. C., for assisting in the technical review of the text.

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READING LIST

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Fire Controlman 3, Vol. 1, NavPers 10163–A
Fire Controlman 3, Vol. 2, NavPers 10164–A
Electricity for FC & FT, Vol. 1 (Chaps. 8–12), NavPers 10170
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Fire Controlman 2, Vol. 2, NavPers 10035–B
Fire Controlman 2, Vol. 3, NavPers 10035–C
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Electronics Technician 2, Vol. 2, NavPers 10191

OTHER PUBLICATIONS

Naval Ordnance & Gunnery (Chaps. 24, 25, 28, 32, 33), NavPers 16116–B
BuOrd Manual, 1943, Chaps. 1A, B, F; 2, 3, 11 (with changes 1–10)

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United States Armed Forces Institute (USAFI) courses for supplementary reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

	Correspondence		**Self-Teaching**
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FIRE CONTROL TECHNICIAN 1 & C

VOL. III

CHAPTER 1

TRANSMISSION LINES

The function of transmission circuits in fire-control equipment is to transmit r-f power and signals from one of the specialized components to another. Among other things, the circuits must provide for the necessary bends and twists in the line and must permit the required relative motion of the components. The transmission lines used to carry r-f power or signals are almost always either hollow-pipe waveguides or coaxial lines.

LOSSES IN AN R-F LINE

To get as much as possible of the transmitter output power to the antenna, and of the received power to the receiver, it is desirable that the losses of the r-f lines be low. There are 3 kinds of losses in r-f lines: (1) the copper loss, or power dissipated as heat in the conductor; (2) the dielectric loss, or power dissipated as heat in the insulation; and (3) the radiation or induction loss, which is power transferred from the line in question to adjacent circuits or into free space. All these losses increase as the frequency increases. To keep them as low as possible, various types of transmission lines have been designed.

TYPES OF TRANSMISSION LINES

There are four types of transmission lines: the open wire, the coaxial line, the two-conductor shielded cable, and the waveguide.

Open wire lines are simple to build, but their induction and radiation losses are excessive at high r-f. A more suitable line at high frequencies is the coaxial line, composed of two concentric conductors separated by an insulating material. Because the electromagnetic field associated with a coaxial line is confined to the space between the inner and outer conductors, neither induction nor radiation loss occurs. Coaxial lines have low attenuation even at very high frequencies and are used extensively at 3,000 Mcps and at all power frequencies. Coaxial lines for use in radar are constructed in flexible and rigid forms.

The two-conductor shielded cable is not widely used as the loads are higher than those of coaxial lines.

Waveguides are used because the losses in a coaxial line become excessive at wavelengths shorter than 10 centimeters. Hollow-tube waveguides can be constructed in a reasonable size for use at these wavelengths.

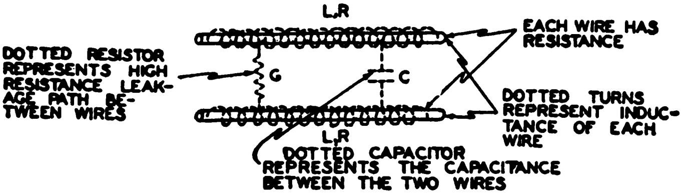
IMPEDANCE OF A TRANSMISSION LINE

When a transmission line is short as compared to the length of the radio waves which it carries, the opposition to a voltage applied to the input terminals is chiefly at the load with only a small amount of voltage being required to overcome the resistance of the line.

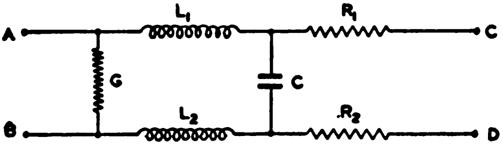
When the line is long as compared to the length of the wave, and if the load is not of a certain correct value, the voltage necessary to drive given amounts of current through the line may differ greatly from that which can be accounted for by the impedance of the load in series with the resistance of the line.

The transmission line has other factors besides resistance which create this effect of increased or decreased input impedance. These factors are inductance in series with the line, capacitance across the line and certain radiation losses. In r-f transmission lines these quantities are distributed throughout the entire line and cannot be separated from each other.

Figure 1–1a shows properties of resistance, inductance, capacitance and conductance combined in a short section of a two-wire transmission line. Actually, the diagram does not


L,R
EACH WIRE HAS RESISTANCE
DOTTED RESISTOR REPRESENTS HIGH RESISTANCE LEAKAGE PATH BETWEEN WIRES
G
C
DOTTED TURNS REPRESENT INDUCTANCE OF EACH WIRE
L,R
DOTTED CAPACITOR REPRESENTS THE CAPACITANCE BETWEEN THE TWO WIRES

a. SHORT SECTION OF TWO-WIRE TRANSMISSION LINE



b. EQUIVALENT CIRCUIT DIAGRAM OF THE SHORT SECTION OF TWC-WIRE TRANSMISSION LINE

R_1 = RESISTANCE OF TOP WIRE
R_2 = RESISTANCE OF BOTTOM WIRE
L_1 = INDUCTANCE OF TOP WIRE
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C = CAPACITANCE BETWEEN WIRES
G = CONDUCTANCE. BETWEEN WIRES

Figure 1–1.—Circuit equivalent of a short section of two-wire transmission line.

represent a real transmission line exactly, since it shows the evenly distributed capacitance as a single lumped capacitor, and the distributed conductance as a lumped leakage path. However, if the section is very short compared to the total length of the line as measured in wavelengths, this approximation is close enough for practical purposes.

CHARACTERISTIC IMPEDANCE OF AN INFINITE LINE

Several of these short sections can be combined into a length of transmission line. Obviously some current flows if a voltage is applied across the input terminals A and B in figure 1–1b. The ratio of the voltage to the current is the impedance Z; $Z=\frac{E}{I}$. In short, the impedance presented to the input terminals of a transmission line is not merely the resistance of the wire in series with the impedance of the load; the effects of series inductance and shunt capacitance on the line itself may overshadow the resistance and even the load as far as the input terminals are concerned.

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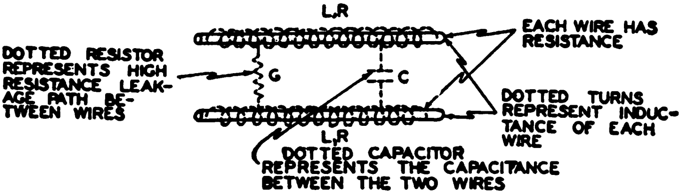
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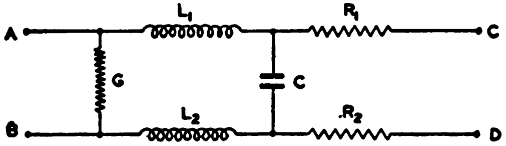

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To find the input impedance of a transmission line, the impedance of a single section in figure 1–1b is determined. This impedance, between terminals *A-B*, can be calculated by the use of series-parallel impedance formulas, provided that the impedance across *C-D* is known. Again the impedance at *A-B* of two sections can be calculated, provided the impedance of the third section is known. This process of adding one section after another can be carried on and on. With the addition of each section the impedance at *A-B* has a new and lower value. However, after many sections have been added, each successive added section has less and less effect on the impedance at *A-B*. If sections are added to the line endlessly, the line is infinitely long and a certain definite value of impedance across *A-B* is finally reached.

The impedance across the input of a theoretically infinite line has a very valuable use. If a resistance load equal to this impedance can be placed on the output end of any short or convenient length of line, the same impedance appears at the input terminals of the line. Only one value of impedance for any particular type size of line acts in this way. This value is called CHARACTERISTIC IMPEDANCE, *Zo*.

STANDING WAVES

When waves travel on a line in both directions simultaneously, the resultant distribution of voltage and current along the line is called a standing wave. The simplest kind of standing wave is that which occurs on a lossless line when the reflected wave has the same amplitude as the incident wave.

The way in which the incident and reflected waves combine to form a standing wave is illustrated in figure 1–2. In figure 1–2a the waves are in phase and the resultant voltage has its maximum amplitude *A* plus *B* at certain positions. In figure 1–2b, a quarter cycle later in time, each wave has traveled a quarter wavelength in its direction of propagation, so that the two waves are now out of phase. They may be subtracted to give a voltage amplitude *A* minus *B* at positions midway between those at which the maximum amplitude (a) occurred. In successive quarter cycles the resultants have the same amplitude as in a and b, but they are opposite in sign. In figure 1–2c is shown the maximum amplitude occurring at each position along the line.

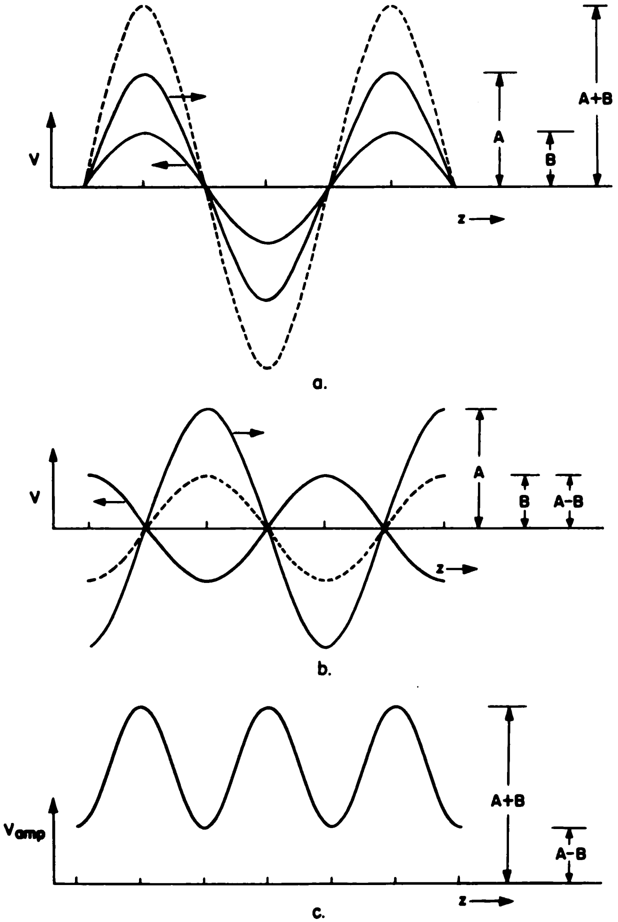


Figure 1–2.—Combination of incident and reflected waves to form standing waves.

Elimination of Standing Waves

The difficulties of making high-frequency measurements are so great that it is usually more practical to calculate the characteristic impedance (Zo) by means of the formula, $Zo=\sqrt{L/C}$. However, a simple method of measuring Zo, although by no means the most accurate, is to terminate the line with a calibrated noninductive variable resistor. When this resistor is varied, the standing waves also vary. When the standing waves are eliminated as measured by an r-f indicator, the line can be considered to be terminated in its characteristic impedance which can be read from the calibrated resistor. This method can be used to determine whether the line is terminated properly for a nonresonant condition. Thus, it is not even necessary to know the value of Zo. It is necessary merely to vary the load on the output end of the line until the standing waves are at a minimum.

WAVELENGTH MEASUREMENTS

Since the maximum and minimum points of a wave must be measured from the output end and occur at points determined by the frequency of the applied voltage, it is convenient to measure the distance of these points in terms of wavelength. Since the distance between two minimum or maximum points is equal to half a wavelength, one wavelength is twice the distance between two adjacent minimum or maximum points as shown in figure 1–3. The distance along the line corresponding to one wavelength is also given by the equation:

$$\text{Wavelength}=\frac{\text{Velocity of propagation}}{\text{frequency}}=\frac{V}{f\sqrt{L/C}}$$

In this formula L and C are respectively the series inductance and the shunt capacitance per unit length, and f is the frequency of the applied voltage.

Because energy travels more slowly on a wire than in free space, the wavelength of a given frequency is shorter on the wire than in space. The electrical length of a wire then differs slightly from the actual length of the wire in

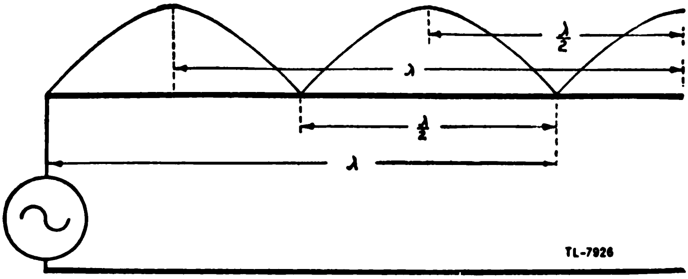


Figure 1–3.—Determination of wavelength by means of standing waves.

terms of the free-space wavelength because the capacitance effects between the wires and ground decrease the velocity of propagation on the line. Also, the spacers and insulating materials used have a dielectric constant greater than air, which increases the effective capacitance, thus also affecting the velocity.

The electrical quarter-wavelengths for various types of lines may be calculated from the formula:

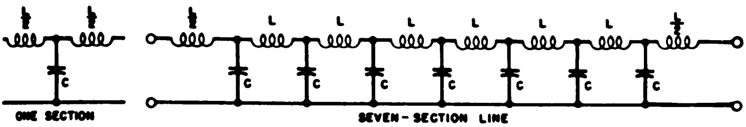
$$l \text{ (in feet)} = \frac{246 \times k}{\text{frequency (in megacycles)}}$$

where l is the quarter-wavelength and k is a constant which depends on the type of line. It is the factor expressing the ratio of the actual velocity of the energy on the line to the velocity of light.

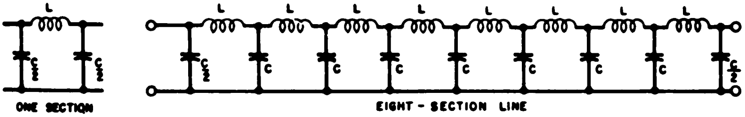
TRAVELING WAVES OF ARTIFICIAL TRANSMISSION LINES

Networks of inductance and capacitance that behave like sections of transmission lines are often used in radar to form rectangular pulses, to delay pulses, or to modify the shares of pulses in special ways. These networks are used instead of actual transmission lines because the lengths of real lines required are too long to be practical—about 1,000 ft of line would be needed to delay a pulse of 1 microsecond. Also, in many applications the characteristic resistance of real lines is too low for convenient use with tubes.

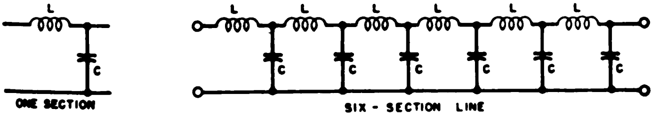
The artificial lines of figure 1–4 are examples of one type of network often used to simulate transmission lines. An



(A) ARTIFICIAL LINE COMPOSED OF T SECTIONS



(B) ARTIFICIAL LINE COMPOSED OF Π SECTIONS



(C) ARTIFICIAL LINE COMPOSED OF L SECTIONS

Figure 1—4.—Examples of artificial transmission lines.

artificial line is a chain of various types of sections, as shown in the figure, each containing series inductance and shunt capacitance.

An artificial line having many sections with a very small inductance and capacitance in each resembles a real line which has inductance and capacitance distributed along its length. If a sinusoidal voltage wave is applied to an artificial line, and if the frequency of the applied voltage is low so that the phase of the wave changes only a few degrees from one section to the next, then the operation of the line is essentially the same as if the inductance and capacitance were uniformly distributed along the line.

If the frequency of the voltage applied to a network is made too high so that the wavelength along the network is short compared with one section, the similarity to a straight line disappears. The critical frequency below which the operation of an artificial line approximates that of a real line is called the cutoff frequency f_{co}; $f_{co}=\frac{1}{\pi\sqrt{LC}}$.

A pulse applied to a lossless real line travels along the line at a definite velocity and with no change of shape.

Essentially, the same thing happens when a pulse is applied to an artificial line, provided that all the important Fourier-series components of the pulse lie below the output frequency of the line.

Figure 1–5 shows the mechanism by which a steep wavefront travels along a real transmission line. The switch *S* is closed to connect the battery of voltage *E* to the terminals of the line. The voltage *E* does not appear instantly at all points along the line. Instead, a wave of voltage, shown in figure 1–5, progresses along the line; the farther a given point is from the battery, the later the time at which the line voltage at that point jumps from *O* to *E*. A current wave travels away from the battery exactly in step with the voltage wave: At all points up to the moving wavefront a current *I* flows away from the battery in the top conductor and a return current *I* flows in the bottom conductor. Plus and minus charges appear on the conductors at each point where voltage exists between conductors, and magnetic flux lines encircle the conductors wherever current flows. The charges and flux lines are indicated in figure 1–5.

The reason that the line, unlike a capacitor of small dimension, cannot charge all at once is that the series induct-

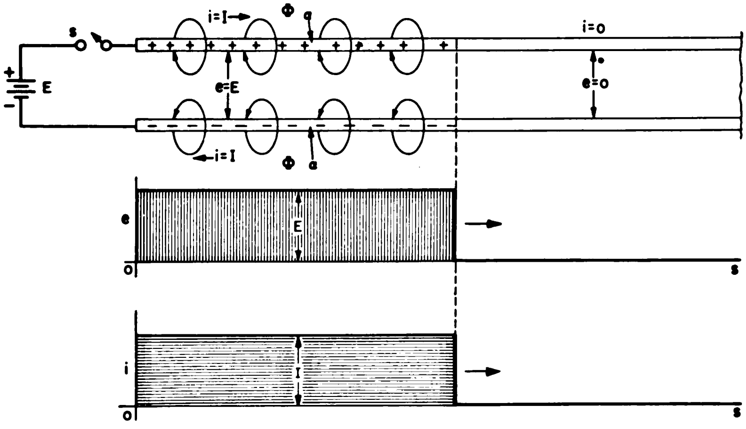


Figure 1–5.—Propagation of a steep wavefront on a transmission line.

ance of the line (associated with the magnetic flux), as well as the shunt capacitance (associated with the electric charge), is important. The voltage wave can progress only as fast as the line current can carry the charge to the wavefront to produce the change in voltage. The current wave can progress only as fast as the voltage that appears across a short section of each conductor at the wavefront can start current in the corresponding section of the line inductance. Therefore, the voltage and current waves must move together along the line.

Let r be the time required for these waves to travel a unit of length along the line, and let c and l be the capacitance and inductance per unit length of the line. Then Ir is the charge that flows from the battery into the line in the time interval r and cE is the charge accumulated on the line at the moving wavefront during the same time interval. Therefore, $Ir=cE$. During the same time interval r, the flux encircling the conductors increase by an amount lI. The voltage E at the wavefront must be generated by the changing flux, and therefore $\mathrm{E}-d(N\phi)/dt$ is the rate at which flux linkages are being produced at the wavefront, or Er is the increase of flux linkages in the interval r. Therefore, $Er=lI$. If the two equations above were multiplied together, and the common factors EI canceled, the value of r is obtained. So r equals the square root of lc. Inductance can be defined as flux linkages per unit current $(N\phi/I)$; therefore, lI is the number of flux linkages associated with the inductance l of a unit length when the current I is flowing in it.

In r-f components of radar systems, sine-wave generators rather than batteries are connected to transmission lines and sine-waves instead of step waves travel along the lines. A fact of fundamental importance is that a wave of any shape is propagated without any change of shape or magnitude along a uniform lossless line at a given speed in the following equation: velocity equals one over the square root of LC, $V=\frac{1}{\sqrt{LC}}\cdot$

The voltage wave is always accompanied by a current wave of similar shape, and at a given instant the ratio Rc of the amplitudes of the two waves at any given point has a value indicated by the equation, $Rc = \sqrt{L/C}$.

APPLICATION OF RESONANT LINES

R-f transmission lines have many uses besides the transmission of power from point to point. A few of these are:

1. Metallic insulators.
2. Wave filters and chokes.
3. Reactors.
4. Impedance-matching devices.
5. Phase-shifters and inverters.
6. Oscillator frequency controls.
7. Line balance converters.

QUARTER-WAVE LINE AS A METALLIC INSULATOR

When a quarter-wave line is shorted at the output end and is excited to resonance at the other end by the correct frequency, there are standing waves of current and voltage on the line. At the short circuit the voltage is zero while the current is maximum. At the input end the current is nearly zero and the voltage is a maximum; therefore the E/I ratio, and thus the impedance, is very large. Since an exceedingly high impedance across the terminals acts like an insulator to another line, at a certain frequency a line can be cut to a quarter-wavelength, shorted at the output end, and used as an insulator at its two open terminals.

QUARTER-WAVE LINE AS A FILTER

Both open and closed quarter-wave resonant lines may be used as wave filters, and more than one filter can be connected between the transmitter and an antenna to eliminate the radiation of undesired frequencies. A quarter-wave filter which is open at the output end and is placed in series with the transmission line offers low impedance to the fundamental frequency. At each odd harmonic such a line is an odd multiple of a quarter-wave and therefore offers little impedance to the odd harmonic; thus it passes the fundamental and odd harmonics along the line to the antenna coupling unit. At even harmonics, however, the length of the open line becomes a half-wave, or some multiple of a half-wave, so the filter offers high impedance to the even harmonics and blocks their passage to the antenna coupling unit.

TRANSMISSION LINE AS REACTANCE

The open end line acts as a capacitive reactance at lengths shorter than a quarter-wave. In fact, at one-eighth-wavelength such a line has a capacitive reactance equal in magnitude to its characteristic impedance. Therefore, an open line less than a quarter-wavelength may be used as a capacitor in open-air installations. At the exact quarter-wavelength, or odd multiple thereof, the open line has zero reactance. As the length of the line is increased beyond a quarter-wave, the line becomes equivalent to an inductor, causing the current to lag. Finally, at a half-wave or multiple half-wavelength the open end line has an infinite reactance.

A closed-end line, on the other hand, acts as an inductive reactance at lengths shorter than a quarter-wavelength. At an eighth-wavelength it has an inductive reactance numerically equal to its characteristic impedance, and at exactly a quarter-wave, or odd multiple thereof, it has infinite reactance. Between a quarter-wavelength and a half-wavelength the line becomes equivalent to a capacitor and, at exactly a half-wavelength, or multiple thereof, the line has zero reactance. Figure 1–6 shows reactance variations for lengths of a transmission line for both the open and closed output end condition.

FREQUENCY CONTROL OF OSCILLATORS

Since quarter-wave short-circuited transmission lines may act as parallel resonant circuits, such lines may be substituted for the ordinary coil-and-capacitor circuits employed in oscillators. The advantage of lines used as tuned circuits

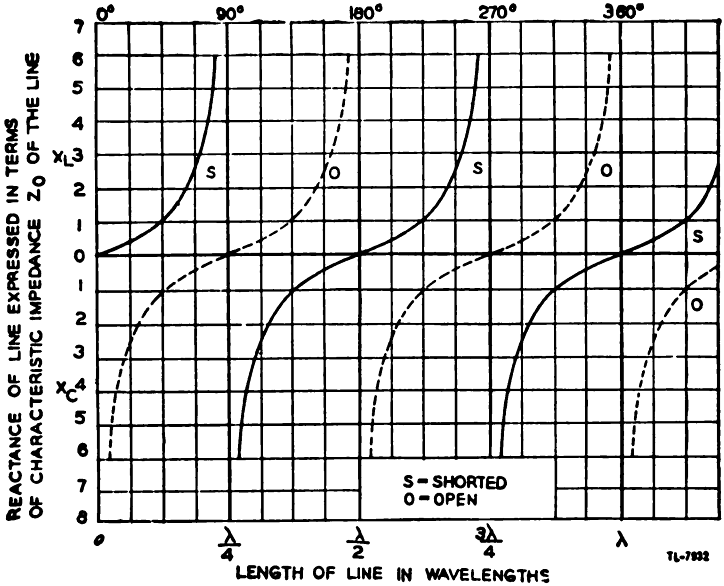


Figure 1—6.—Transmission-line reactance graph.

in oscillators are high *Q*, low losses and efficient oscillations at frequencies above those readily attainable with tank circuits made of ordinary coils and capacitors.

The *Q*, or figure of merit of a line, is a ratio of its inductive reactance to its resistance. If the resistance is low for a given value of reactance, the *Q* is correspondingly high. The degree to which a resonant circuit controls the stability of frequency depends upon its *Q*, so that if a high degree of stability is desired, the tuned circuit must have a high *Q*. The *Q* of a concentric line is maximum when the ratio of the inner diameter is equal to 4.22. The *Q* of a two-wire line is a maximum when the ratio of the spacing of the wires to the radius of one wire is 6.19. The *Q* of any line is also best at an effective electrical length of approximately a quarter-wavelength, and it may be increased markedly in ultra-high-frequency applications by silver-plating the lines, since skin effect forces most of the current to flow in the surface of the metal.

Certain transmission line characteristics are desirable in oscillator circuits. In a single tube oscillator the concentric line is used frequently. For push-pull circuits a balanced two-wire line or two concentric lines may be used. The concentric line type has the added advantage that the inner conductor is shielded by the conductor which reduces unwanted radiation to a minimum.

QUIZ

1. Any length of line can be made to respond like an infinite line if
    a. reflections along the line result in standing waves.
    b. it is terminated in its characteristic impedance.
    c. the load is infinite, as with an open-end line.
    d. the line is short-circuited.
2. In an infinite length of line fed from an a-c source, voltage and current waves are
    a. standing waves in phase throughout the line.
    b. standing waves out of phase throughout the line.
    c. traveling waves out of phase throughout the line.
    d. traveling waves in phase throughout the line.
3. The minima of current or voltage along a standing wave can never be zero because
    a. heat and radiation losses in the lines use some energy.
    b. the electric and magnetic fields produced are always interchanging energy.
    c. both current and voltage waves are positive.
    d. the line acts like a resonant tank circuit in its handling of energy.
4. In u-h-f antenna systems, transmission lines are employed
    a. as impedance-matching devices.
    b. as coupling devices.
    c. to vary phase relations between elements.
    d. in all of the above ways.
5. When the last resonance point of voltage is less than a quarter-wavelength from the output end of a line, the load is
    a. resistive.
    b. its characteristic impedance.
    c. inductive.
    d. capacitive.

6. A quarter-wavelength resonant line shorted at the output end can be used as an insulator and support because it represents a high impedance to
   a. all frequencies in the r-f wave.
   b. the fundamental frequency and all harmonics.
   c. the fundamental frequency and all even harmonics.
   d. the fundamental frequency and all odd harmonics.

7. A satisfactory method to suppress even-harmonic radiation without suppressing the fundamental is to use
   a. a shorted quarter-waveline placed in series with the transmission line.
   b. a shorted quarter-waveline placed across the transmission line.
   c. an open quarter-wave stub and a shorted quarter-wave stub both in series with the line.
   d. an open quarter-waveline placed across the transmission line.

8. The use of the shorted quarter-wave resonant section for impedance matching is based on the fact that
   a. parallel resonance results in a high impedance.
   b. the phase is inverted 180° between the shorting bar and the open end.
   c. at any point on the section the impedance is Z_0.
   d. the impedance of the section varies from zero at the short to a maximum value at the open end.

9. Artificial transmission lines are NOT used to
   a. block or pass certain frequencies.
   b. produce trigger pulses for magnetrons.
   c. obtain a desired phase delay.
   d. transmit energy to an antenna.

10. Compared with a coaxial cable of the same size, the hollow waveguide has the advantage of
   a. greater power handling capacity.
   b. easier shipboard installation and operation.
   c. lower cutoff frequency.
   d. better shielding.

True—False

11. A short circuit may represent a condition of zero impedance or high impedance, depending on the length of the line.

12. The characteristic impedance of a properly terminated line designed to carry r. f. is almost a pure resistance.

13. An open-end line that is an odd multiple of a quarter-wave in length acts like a parallel-resonant circuit.

14. The reactance of an open-end line that is an eighth-wavelength long is capacitive and is numerically equal to the characteristic impedance of the line.

15. A simple way to determine the approximate characteristic impedance of a line is to terminate the line with a variable noninductive resistor adjusted to produce a minimum standing wave ratio.

CHAPTER 2

WAVEGUIDES AND CAVITY RESONATORS

The term "waveguide" is applicable to all types of transmission lines in the sense that they are being used to direct waves regardless of whether the line is composed of a single conductor, two or more conductors, a coaxial line, a hollow metal tube, or a dielectric rod. However, usage has limited the meaning of the word to the hollow metal tube and the dielectric transmission line.

TYPES OF WAVEGUIDES

Waveguides may be classed according to cross-section as rectangular, elliptical, or circular and they may be classed according to material as metallic or dielectric. Dielectric waveguides are seldom used because the losses for all known solid dielectric materials are too great for efficient transmission. Of the 3 types of hollow-tube waveguides, the rectangular cross-section type is most commonly used.

Advantages and Disadvantages

Among the advantages of waveguides are that hollow-tube waveguides are usually filled with air and therefore have negligible dielectric loss. The electromagnetic field is confined to the space inside the pipe; therefore, there is no radiation loss.

There is a copper loss in waveguides, but this loss is smaller than that in a coaxial cable of equal size, largely because the inner conductor in which most of the loss occurs is eliminated.

The power which can be transmitted in a hollow-tube waveguide is greater than in a coaxial cable of equal size. The construction is simple and rugged; the pipe is not easily damaged by continued vibration or the shock of gunfire.

The attenuation in waveguide above cutoff frequency is less and the efficiency of transmission is greater than in comparable coaxial line. Figure 2–1 illustrates the variation of attenuation with frequency for both a 3-inch cylindrical waveguide operating on its dominant mode and the lowest mode for which the attenuation varies inversely with frequency and a 3-inch coaxial line.

Note, in figure 2–1, that the attenuation of the waveguide becomes very great at approximately 2,500 mc. That frequency is called the CUTOFF FREQUENCY for this particular guide because the guide cannot transmit frequencies lower than this value.

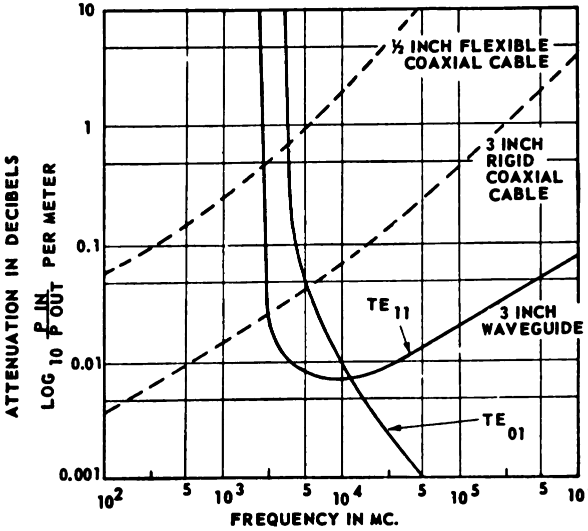


Figure 2–1.—Attenuation of a 3-inch cylindrical waveguide compared to that of two coaxial lines.

The attenuation increases as the frequency increases for all the lines (except for the TE_{01} mode) because the skin effect forces the current to flow in a progressively thinner layer, causing the copper losses to increase. However, note that the attenuation in the waveguide is considerably less than that of either coaxial line for frequencies above cutoff. The attenuation varies according to the mode in which the waveguide is operating, and there is a series of modes for circular waveguides (TE_{01}, TE_{02}, TE_{03}, etc.) for which attenuation continuously decreases as the frequency increases indefinitely.

Disadvantages of waveguide include the fact that the minimum size of the waveguide that can be used to transmit a certain frequency is proportional to the wavelength at the frequency. The proportionality depends upon the shape of the waveguide and the manner in which the electromagnetic fields are set up within the pipe. In all cases there is a minimum frequency, called the cutoff frequency, that can be transmitted. The lowest cutoff frequency depends on the inside width of the guide (fig. 2–2). The wavelength, λco, corresponding to the cutoff frequency is equal to twice the inside width of the guide.

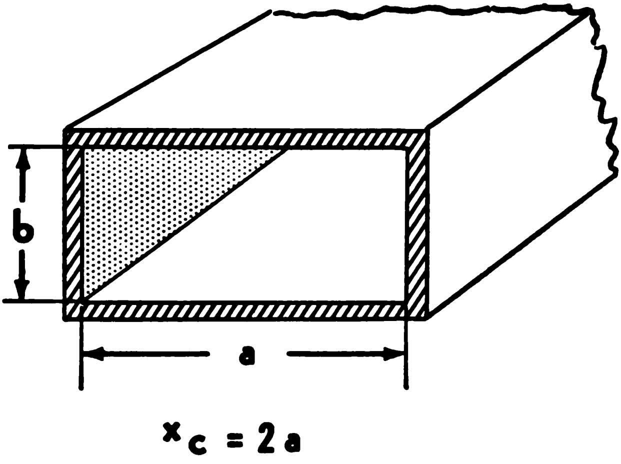


Figure 2–2.—Waveguide section; cutoff frequency equals 2a.

As a result of this fact, waveguides are not used extensively at frequencies below approximately 3,000 mc. (10 centimeters) because at those frequencies the guide would be too large. For example, to transmit 10-centimeter waves, a rectangular waveguide would have to be wider than 5 centimeters. For 1-meter waves the waveguide would have to be at least 2½ feet wide, and for 10 meters, 25 feet wide.

The installation of a waveguide transmission system is somewhat more difficult than for other types of lines. The radius of bends in the line must be greater than two wavelengths to avoid excessive attenuation, and the cross section of the waveguide must be maintained uniform around the bend. These difficulties hamper installations in restricted spaces. If the guide is dented, or if solder is permitted to run inside the joints, the attenuation of the line is greatly increased. In addition to the increased attenuation that they cause, dents and pieces of solder also reduce the break-down voltage of the waveguide and cause standing waves on the waveguide. Although such faults may not cause arc-over in the guide, they limit the power handling capacity of the system and make the possibility of arc-over more likely. Thus, unless great care is exercised in the installation, one or two carelessly made joints may nullify completely the initial advantage obtained from the use of the waveguide.

ELECTROMAGNETIC FIELD IN SPACE

James Maxwell, an English physicist, developed a theory for explaining what happens when an alternating magnetic field exists in a dielectric such as air. His theory and research completed the union between electricity and magnetism and provided the mathematical tools necessary for understanding electromagnetic radiation. Maxwell said that the molecules of a dielectric contain positive and negative charges, as does a conductor. Unlike a conductor, however, the charges are bound together with elastic bonds. When an electric field is applied across a dielectric, the positive and negative charges are displaced and the dielectric becomes polarized. Since the electrons cannot leave the atoms of the dielectric, no direct current can flow. But since the positions of the electrons are varied, the motion of the charges is an alternating current that flows only while the electric field is changing. For obvious reasons the current is called displacement current.

Displacement current is very similar to conduction current, except that it cannot exist as direct current. Like conduction current the displacement current produces a magnetic field. This concept of Maxwell's assisted greatly in completing the picture of the energy relation in an electromagnetic wave. An alternating current in a conductor produces an alternating magnetic field in the space around the conductor. (Oersted). The alternating magnetic field in space produces an alternating electric field in space (Faraday). The electric field in space produces a displacement current, which in turn produces a magnetic field (Maxwell). It is thus seen that some of the energy in an alternating conduction current is changed into a magnetic field, which in turn is changed into an electric field and then back again into a magnetic field.

Maxwell was the first to derive the complete mathematical expressions for the foregoing phenomena. These expressions are called Maxwell's equations and are the basis for modern electromagnetic theory. From these equations Maxwell deduced that: (1) an electromagnetic wave in free space consists of an electric (E) and a magnetic (H) field that are 90° out of phase, (2) the E and H fields are at right angles to each other, and (3) the wave propagates in a direction perpendicular to both E and H fields with the velocity of light. These important facts about electromagnetic waves were proved experimentally after being deduced theoretically by Maxwell.

MODES OF PROPAGATION

In a water wave each water particle moves in a direction at right angles to the direction of propagation of the wave. A water wave is said to be a tranverse wave. Sound waves are longitudinal waves—that is, each particle in the medium vibrates along the direction of propagation. The propagation of electromagnetic waves is classified in modes according to the orientation of the E and H vectors with respect to the direction of propagation. In waveguides the E or H vector may have a component longitudinal to the direction of propagation.

The mode of propagation of an electromagnetic wave in free space is characterized by both *E* and *H* vectors perpendicular to the direction of propagation. This kind of wave, shown in figure 2–3a, is called a transverse electromagnetic or *TEM* wave.

In figure 2–3 the *E* lines are solid lines and the *H* lines are dotted. In perfectly conducting transmission lines the electric and magnetic fields between the conductors are entirely perpendicular to the direction of propagation, as shown in figure 2–3b for a parallel wire line, and in figure 2–3c for a coaxial line. *TEM* waves are sometimes called transmission-line waves.

If a wave enters a waveguide, as shown in figure 2–3d, point *A* on a wavefront of positive polarity is reflected at point *B* with a change to negative polarity. In the time it takes point *A* to travel to point *C*, point *D* on a negative wavefront

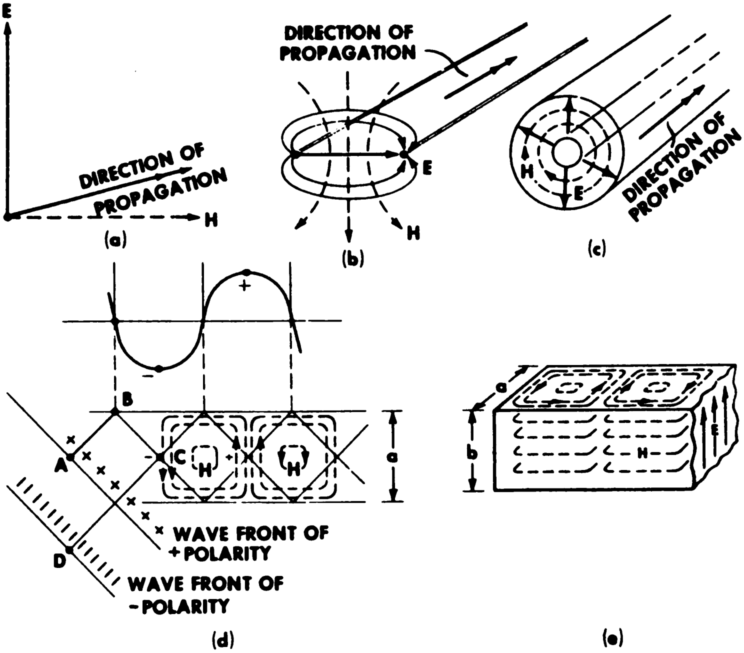


Figure 2–3.—Orientation of the *E* and *H* vectors in electromagnetic waves.

arrives to reinforce the field at *C*. The electric field is zero at the conductor and a maximum at the center of the guide. The angular relations are not quite simple as shown because the wavelength of the wave in the guide is different from that of the wave in free space. The magnetic-field distribution in the guide is shown by the dotted lines in figure 2–3d. The magnetic field is zero in the center and maximum at the side walls where it is nearest to the currents on the walls.

A waveguide may have many modes. The dominant mode is the one with the lowest cutoff frequency. It depends only on the dimensions of the guide and does not depend on how the guide is excited. If the wave in the guide has its electric field (E) transverse or perpendicular to the axis and no component of E along the axis of the guide, the wave is said to be a TE (transverse electric) wave. Since the TE wave has a component of the H field longitudinal to the guide, a TE wave is sometimes called an H wave. Figure 2–3e shows the electric-field and magnetic-field distribution in a waveguide operating with the TE_{01} mode, the dominant mode for a rectangular guide.

If the closed loops of the magnetic-field pattern are in planes perpendicular to the axis of the guide, the wave is said to be a TM (transverse magnetic) wave. Since the TM wave has a component of the E field longitudinal to the guide, a TM wave is sometimes called an E wave.

RECTANGULAR-WAVEGUIDE DIMENSIONS

The dimensions of rectangular waveguides for radar use are usually chosen so that only the dominant wave can be transmitted. Any higher order waves set up within the guide are then attenuated rapidly in the vicinity of their source. Higher order waves may originate at discontinuities (such as bends, twists, matching devices, and transmit-receiver devices) which are always present in any practical installation. Elimination of higher order waves is desirable because of the extreme difficulty of designing guide terminations and matching devices to operate satisfactorily with respect to more than a single wave type.

Choosing *a* and *b* (width and height of cross-section of a waveguide) so as to prevent $TE_{2,0}$ and $TE_{0,1}$ waves also insures that other higher order transverse-electric and transverse-magnetic waves will not be propagated. Factors that effect the choice of guide dimensions within the limitations are the attenuation and the amount of power that the guide must transmit.

From the attenuation curve of figure 2–4 it may be seen that, in order to keep the attenuation low, the width of the guide's cross section should be chosen so that the operation is well above the cutoff frequency and the height should be made as large as possible.

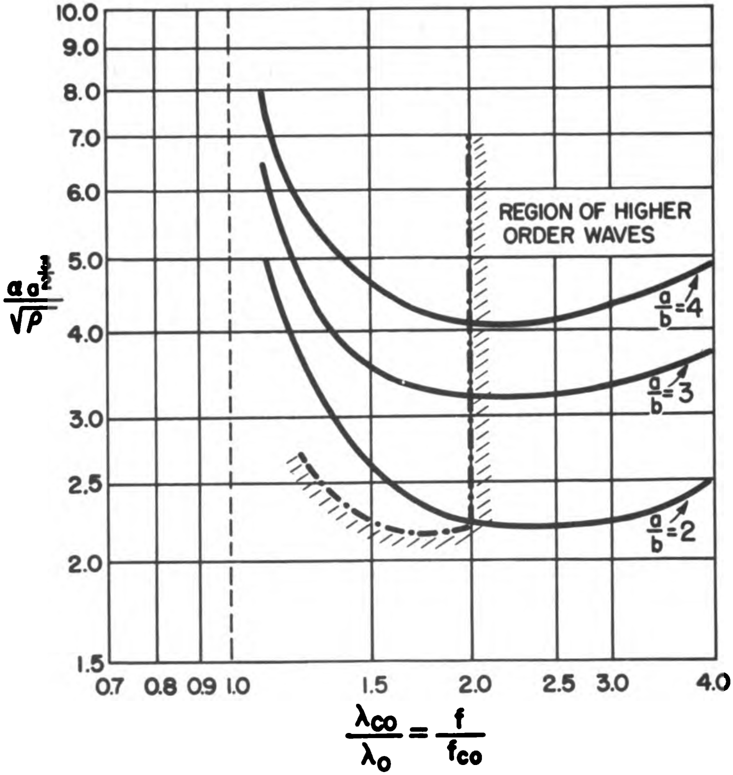


Figure 2–4.—Attenuation curves for $TE_{1,0}$ wave in a rectangular waveguide.

IMPEDANCE-CHANGING DEVICES

Often in radar r-f transmission systems are not perfectly matched by the load devices. The standing waves that result are undesirable in waveguides, as they are in 2-wire lines, because of the associated increase in power loss, reduction of power capacity, and increase of frequency sensitivity. Impedance-changing devices are therefore introduced near the source of reflected waves to provide a standing-wave ratio nearly equal to unity over the major part of the system. Impedance-changing devices are employed also near the source to provide a load impedance for the source of optimum value.

The types of matching devices used in waveguides are the tuning screw, which is a metal screw penetrating the top or bottom wall of the waveguide, and the iris, which is a perforated metal diaphragm placed across the guide. Irises cancel out the reactive component of the load impedance in two ways: (1) placed across the voltage side of the waveguide, it acts as inductive reactance; (2) placed across the frequency side of the waveguide, it acts as capacitive reactance.

RESONATORS

All resonators, whether reactive networks, transmission lines, or cavities, have certain natural frequencies of oscillation. A natural frequency is a frequency for which oscillations in a lossless resonator can be sustained, once started, even though the resonator, is completely isolated from all sources of power. Some resonators have only a single natural frequency; others may have several or even infinitely many. Each natural frequency oscillation is called a natural mode or resonant mode. The term mode signifies a manner of oscillation. The various modes occur at different frequencies and, in general, cause different patterns of voltage and current or of electric and magnetic fields in the resonators. A description of a natural-mode oscillation should therefore include a specification of (1) the frequency, (2) the voltage and current patterns, or the electric and magnetic field patterns, and (3) a measure of the amplitude of the oscillations.

Figure 2–5 shows the simplest network resonator—a tuned circuit consisting of a single inductor and capacitor. In this circuit an oscillation once started (by charging the capacitor before connecting it to the inductor, for example) will persist indefinitely if the elements are lossless. The frequency must be such that L and C carry equal currents and have equal terminal voltage; that is, the inductive and capacitive reactance must be equal. To state this in formula form: $f_0 = \frac{1}{2\pi\sqrt{LC}}$. Because the reactances are equal at only a single frequency, the circuit of figure 2–5 has but one natural frequency and hence one mode of oscillation.

The oscillation in the network of figure 2–5 involves only a single voltage and a single current, denoted by e and i. This continuous oscillation of a constant amount of energy between electric field and magnetic field is characteristic of all types of lossless resonators. The amount of energy involved depends upon the amplitude of the oscillations.

Resonators for use in the microwave range of frequencies take the form of totally enclosed metallic chambers, or cavities. Cavities may be made from thin sheets of copper, or from other metals plated with silver, copper, or gold on the

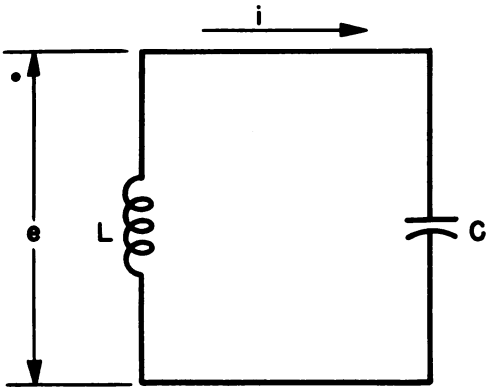


Figure 2–5.—Resonator composed of one inductor.

inside. Cavities for precision measurements of frequency often are made by hollowing out solid blocks of metal so that the dimensions do not change.

An important difference between the resonant cavity and the resonant tank is that the tank resonates only at a single frequency, whereas the cavity is resonant at a fundamental frequency and at harmonic frequencies, and, in addition, may be resonant at other frequencies corresponding to other modes of operation. Therefore, great care must be exercised in order to be certain of single frequency operation. This is especially important when a cavity is used as a wavemeter.

Because of the large conducting surface of a cavity, the losses are small, making the Q of resonant cavities very high. Q's of 20,000 to 50,000 are possible in resonant cavities. Silver plating the inner surface of the cavity increases the Q (if the plating is not porous) because of lower I^2R losses.

Since the energy is stored in the fields of the cavity and the major losses occur in the surface of the bounding walls, it may be concluded that the greater the ratio of volume to bounding surface area, the greater the Q will be in a cavity resonator. Therefore, simple cavities such as spheres, cylinders, and rectangular boxes usually have higher Q's than the more complex cavities.

COUPLING AND MATCHING

There are three principal ways in which energy can be put into and removed from waveguides and cavity resonators. The first is by placing a small loop of wire so that it "cuts" or couples the H lines of the magnetic field as in a simple transformer. The second is by an antenna or probe which can be placed parallel to the E lines of the electric field. In this case the probe has an electric field of its own which adds to or detracts from the electric field of the guide or cavity and thus permits energy to be delivered or removed. The third method is to link or contact the fields inside of the guide or cavity by external fields through the use of slots or holes in the walls.

Figure 2–6 shows loop coupling (inductive coupling) to

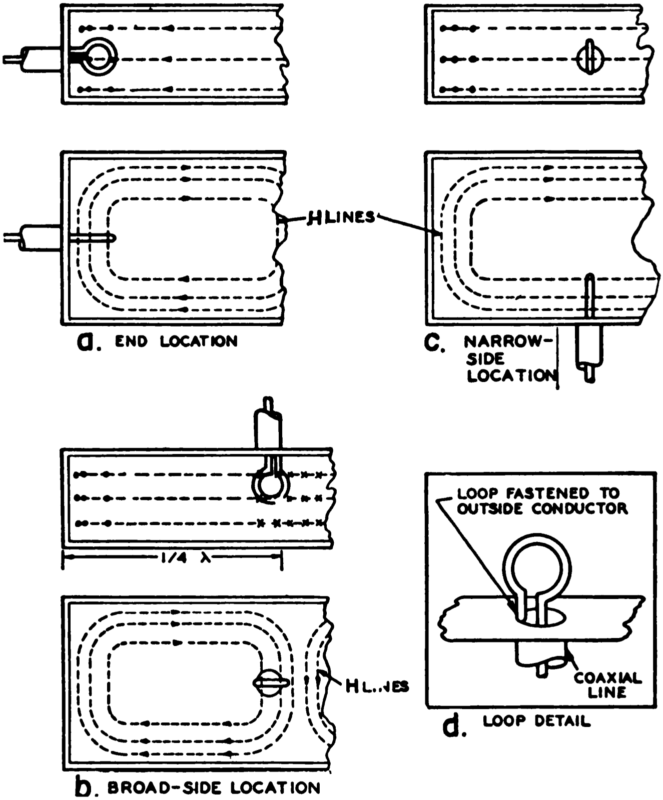


Figure 2–6.—Magnetic coupling from coaxial line to waveguide.

the *H* lines. The loop may be placed anywhere on the guide or cavity, as shown in figure 2–6a, b, c, as long as it can link the magnetic field. Therefore, it is usually placed at a location where the *H* lines are at a maximum. If less coupling is desired, the loop can be rotated so that a smaller number of lines can go through it or it can be shielded or moved to a position in the guide where there are fewer lines.

Brief Summary of Couplings

1. Loop: made to the voltage side and is maximum when it is vertical. Vary the amount of coupling by varying the loop.

2. Probe: made to the frequency side. Pushing the probe further in the waveguide makes a tighter coupling.
3. Slot: made to the voltage side. The size of the slot determines the amount of coupling—the bigger the slot the more the coupling.

There are numerous variations of these methods of coupling. A waveguide may be made to act as a radiator by the simple expedient of leaving one end of the guide open. This method is not very satisfactory because, the energy is radiated in a very broad beam and there is considerable reflection within the guide from the open end. This action results in the establishment of standing waves in the guide.

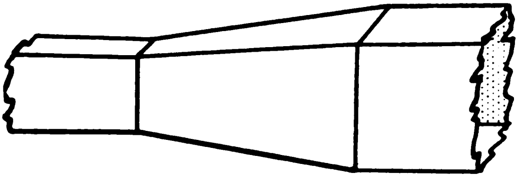


Figure 2–7.—Tapered waveguide transition section.

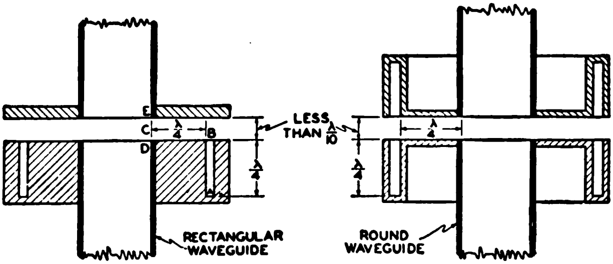
If the open end of the waveguide is flared in the shape of a horn, the characteristic wave impedance match of the guide to free space is considerably improved, the energy is radiated in a more concentrated beam, and less energy is reflected back along the guide. In order to obtain a very sharp beam the flare must be gradual and the mouth of the horn must be very large. To fulfill both these requirements, the horn must be very long and therefore this method is not very desirable.

Essentially the horn constitutes an impedance-matching section between the waveguide transmission line and the earth's atmosphere, which may also be regarded as a waveguide. Thus, the horn is a transition section between a small and a large waveguide. When it is necessary to connect waveguides of different sizes together, the sudden change in size may cause reflections. One means of avoiding this is to use a slowly tapering section (horn) to make a smooth transition as shown in figure 2–7.

The more gradual the taper, the better is the transition. Tapered sections may also be used for transition between waveguides of different shapes—rectangular and round.

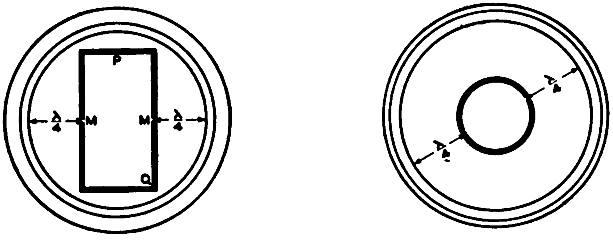
Another method of achieving an impedance match when joining two waveguides involves the use of a resonant cavity. The cavity may be coupled to the waveguide by means of slots. Proper choice of the location and shape of the slots make it possible to match impedance. This method of coupling has the disadvantage of being frequency sensitive.

When connecting two waveguide sections, it is often necessary to turn corners or to rotate the fields of the guide so that they are in the proper direction for matching. If it is necessary to join two waveguide sections in such a way as to allow for expansion or other movement, a choke joint is usually used.



CROSS SECTION VIEW

a.



END VIEW

b.

Figure 2–8.—Choke joints in waveguides.

Figure 2–8 illustrates a choke joint for rectangular waveguides. The choke flange has in it a circular slot a quarter-wavelength deep. The flange is designed so that the middle of the broad face of the waveguide is a quarter-wavelength from the edge of the slot, point *M* in figure 2–8b. The circuit at *A* reflects as a high impedance at *B*, figure 2–8a. This high impedance is transformed to a low impedance at *C* because of the quarter-waveline from *B* to *C*. Thus, the choke joint effectively connects the point *D* and *E* even though there is no direct metallic connection between them. The choke joint is relatively ineffective at points such as *P* and *Q* since a high impedance is reflected between the ends of the two waveguides at these points. However, since r-f voltage is very low at these points, there is little tendency for energy to leak out of the joint. The choke joint for a rectangular guide is thus fully effective only at the point where the r-f voltage is a maximum.

Another problem of impedance matching is that of terminating the waveguide without radiation of reflections. This is important, for example, in a directional coupler. Figure 2–9 shows methods of termination. In part **A** of figure 2–9 a longitudinal partition of resistive material is introduced to absorb the incident energy. The partition is tapered to prevent reflection, that is, to achieve an impedance match.

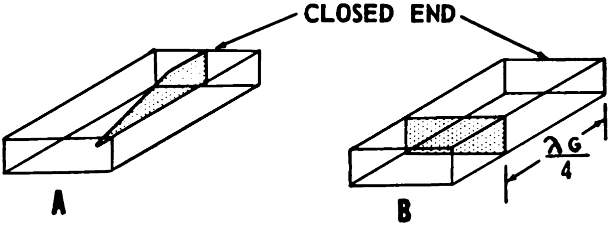
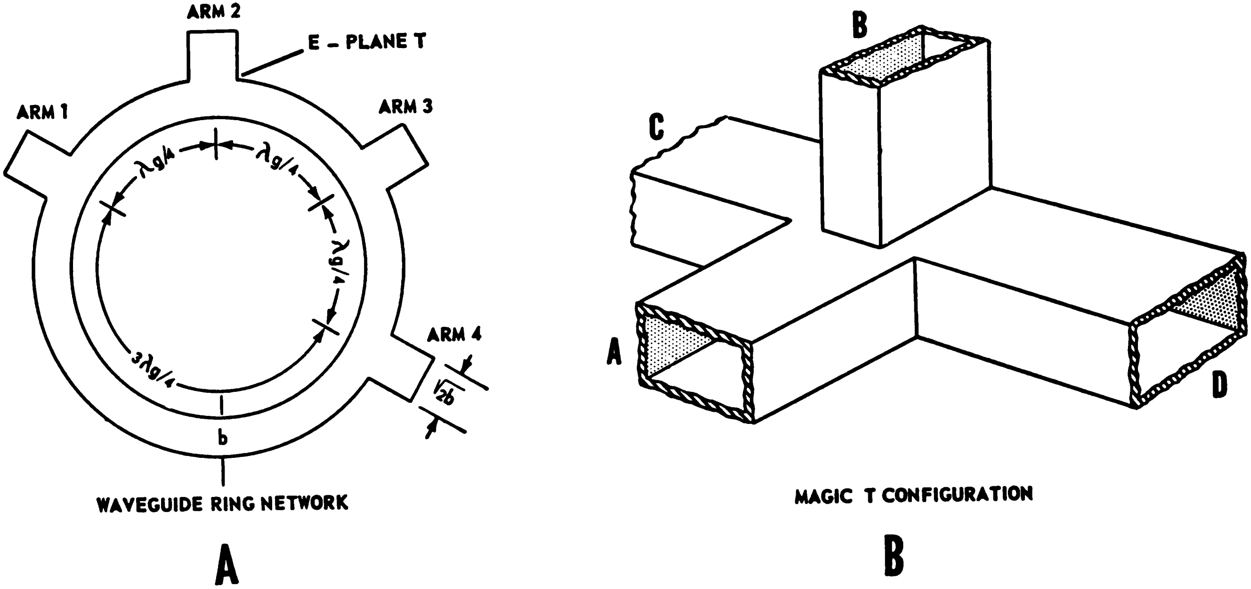


Figure 2–9.—Waveguide terminations.

Part B of figure 2–9 shows the use of a transverse partition of resistive material. To be effective this partition should be located a quarter-wavelength from a shorted end of the guide, and it must have a resistance-per-square equal to the wave impedance for the guide. Wave impedance is the ratio of the transverse electric and magnetic fields. Resistance-per-



WAVEGUIDE RING NETWORK

A

MAGIC T CONFIGURATION

B

Figure 2–10.—Waveguide network. A, Ring: B, magic-T.

square means the resistance measured between the surface of a thin sheet of resistive material.

Figure 2–10A illustrates a waveguide ring network having selective properties that are dependent upon the spacing of the arms. If power is supplied to arm *1*, no power is coupled out of arm *3* because wave interference short-circuits junction *3*. The transformations through the ring result in impedance matches looking into arms *2* and *4* if the characteristic impedance of the ring is 0.707 of the characteristic impedance of arms *2* and *4*.

Figure 2–10B illustrates a magic-T waveguide network used to supply power to the two side outlets *A* and *B* from the input *C*. In this arrangement the side outlets *C* and *D* have the same length and are terminated in the same load impedance. Power input at *A* divides at the junction and flows to *C* and *D* in equal amounts with no output at *B*.

The magic-T junction is used to feed the balanced crystals. Outlet *A* is called the H-plane arm and is attached to the narrow side of the guide. Outlet *B* is called the E-plane arm and is attached to the broad side of the guide. Because of the orientation of the *E* and *H* fields, a wave sent into the H-plane arm excites a wave in the main guide but not in the E-plane arm. Similarly, a wave sent into the E-plane arm excites a wave in the guide but not in the H-plane arm. Therefore, the device transmits power to two lines from each of two independent inputs that are coupled together. By putting the crystals on the guide, the two crystals can be excited by both local oscillator and the signal.

QUIZ

1. Metal partitions or irises may be used inside a waveguide to
   - a. increase the group velocity.
   - b. measure the wavelength.
   - c. increase the arc-over voltage rating.
   - d. change the impedance of the waveguide.

2. If a probe is used to obtain maximum coupling into or out of a waveguide, it should be
   - a. parallel to the H lines.
   - b. parallel to the E lines.
   - c. parallel to the direction of propagation.
   - d. a half-wavelength from the closed end of the guide .

3. Compared with a coaxial cable of the same size, the hollow waveguide has the advantage of
   - a. greater power handling capacity.
   - b. easier shipboard installation and operation.
   - c. lower cutoff frequency.
   - d. better shielding.

4. A cavity resonator is characterized by
   - a. a traveling-wave mode pattern.
   - b. its ability to resonate at only one mode.
   - c. the E_{max} and H_{max} being a quarter-wave apart and 90° out of phase.
   - d. all of the above.

5. Two waveguides of different impedances may be coupled by
   - a. a flared section designed particularly for impedance matching.
   - b. a coaxial line between the terminals.
   - c. a resonant cavity with openings at the coupling ends.
   - d. all of the above.

6. At microwave-lengths the horn radiator is used because of
   - a. its impedance-matching properties.
   - b. its small size and adaptability to various feedlines.
   - c. its usefulness over a wide frequency range.
   - d. all of the above characteristics.

7. Irises may be used to
   - a. cancel out the reactive component of the load impedance.
   - b. act as an inductive reactance.
   - c. increase capacitive reactance.
   - d. all of the above.

8. For frequencies below 3,000 megacycles per second, hollow waveguides are not used because
   a. skin effect would limit the current carried.
   b. the physical dimensions would be prohibitive.
   c. the cutoff frequency is above 3,000 megacycles.
   d. impedance matching becomes difficult.

9. A pickup loop placed within a cavity-resonator for maximum coupling should be placed
   a. at a point of maximum *H* lines.
   b. with its plane perpendicular to the *E* lines.
   c. at a point of maximum *E* lines.
   d. with its plane parallel to the *H* lines.

10. Energy can be put into and removed from waveguides and cavity resonators by
    a. loop coupling.
    b. a probe which is placed parallel to the *E* lines of the electric field.
    c. slot coupling.
    d. all of the above.

True—False

11. In general, directivity of a horn radiator varies directly with the size of the aperture.

12. In waveguides magnetic flux lines which are always perpendicular to the *E* lines must form complete loops.

13. If the guide is dented, or if solder is permitted to run inside the joints, the attenuation of the line is greatly decreased.

14. Standing waves in waveguides cause an increase of power loss.

15. The dominant mode of a waveguide is the one with the lowest cutoff frequency.

CHAPTER 3

MICROWAVE COMPONENTS

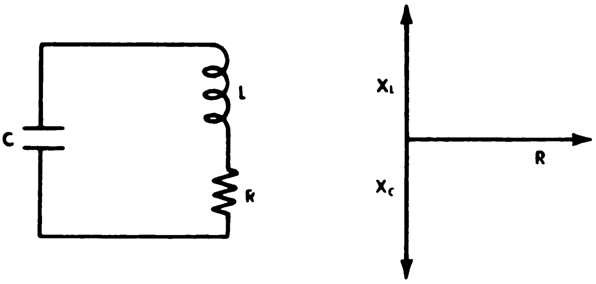
NEGATIVE-RESISTANCE OSCILLATORS

A parallel resonant L–C circuit is shown in figure 3–1. At resonance the reactance of the inductor is equal and opposite to that of the capacitor, and the vector sum of the reactance is zero. However, there is always resistance in the circuit because all circuit elements have some resistance. For example, the inductor has a d-c resistance. The resistances in the circuit cannot cancel each other as can the reactance. When current flows through the resistances, there is a loss of power. In order to produce sustained oscillations it is necessary to add power to the circuit. The power added must have the proper magnitude and polarity to offset the power losses in the circuit. The addition of power to a resonant circuit for the purpose of producing sustained oscillations is called regeneration or positive feedback.

The power introduced by positive feedback equals the power losses in the resistances of the resonant circuit. The feedback may be said to have canceled the "positive" resistances with a "negative" resistance. This concept of negative resistance is very useful in analyzing the operation of many electronic circuits.

The voltage-current characteristic of a resistor is a straight line as shown in curve *A* of figure 3–2. The value of the resistor can be found from the slope of the curve. The slope and value of the resistor of curve *A* are positive.

Curve *B* of figure 3–2 shows the characteristics of a fictitious negative resistance of the same absolute magnitude as



RESONANT CIRCUIT

PHASE RELATION
OF THE IMPEDANCES

Figure 3–1.—A parallel-resonant L-C circuit.

that of the resistor. Note that as the voltage applied to a negative resistance increases, the current decreases. Any device that has a characteristic curve with a negative slope may be said to have a negative resistance.

In feedback oscillators a portion of the resonant tank, or a portion of the signal from a later resonant stage, is fed back to the input. As distinguished from feedback oscilla-

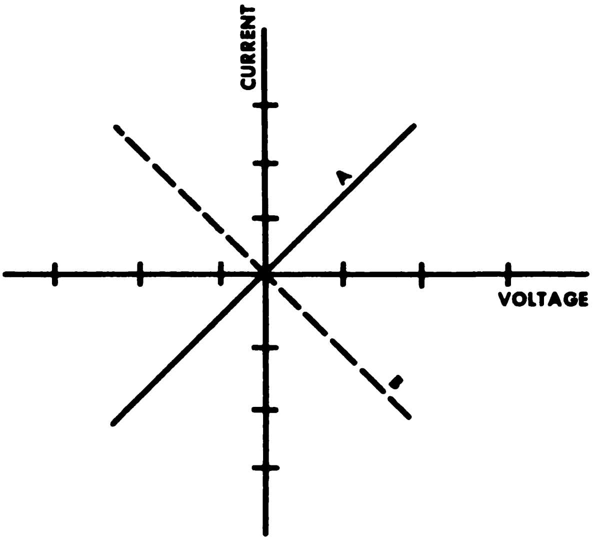


Figure 3–2.—Voltage current characteristic of a resistor and a fictitious negative resistance of equal value.

tors, there is a class of oscillators in which a negative resistance is obtained directly from a characteristic of a tube or other circuit element and not from feedback. Oscillators of this type are called negative-resistance oscillators.

Types of Negative-Resistance Oscillators

The negative-resistance characteristic just described is found, among other places, across an electric arc. A resonant circuit, such as *L* and *C* in figure 3–3, oscillates if connected across a spark gap and if a spark is made to jump the gap. Spark-gap oscillators of this type were used in the earliest experiments on electromagnetic waves before vacuum tubes were developed. They are still used experimentally.

Negative-resistance oscillators using vacuum tubes are classified as dynatron oscillators, transitron oscillators, and negative-resistance push-pull oscillators.

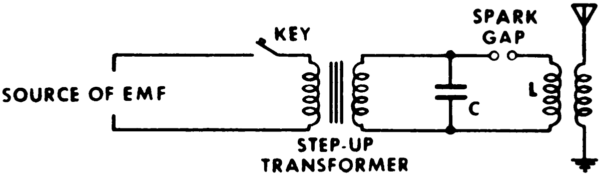


Figure 3–3.—A spark transmitter.

DYNATRON OSCILLATOR

The dynatron oscillator produces a negative resistance because of secondary emission. A portion of the characteristic curve of a tetrode has a negative slope because of secondary emission at the plate. The dynatron oscillator makes use of this negative-resistance portion of the characteristic of a tetrode.

Secondary electrons are ejected from any metal when the metal is bombarded with electrons. The suppressor grid of the pentode was added to suppress the secondary emission at the plate of a vacuum tube. Since there is no suppressor grid in the tetrode tube, the electrons emitted from the plate are attracted to the positive screen. The normal plate cur-

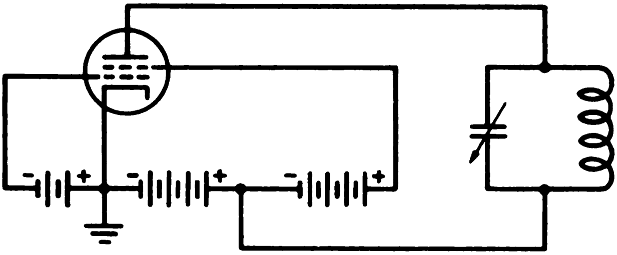


Figure 3–4.—Circuit of a dynatron oscillator.

rent of the tetrode is, therefore, reduced because of the secondary electrons which leave the plate.

The circuit of a dynatron oscillator is shown in figure 3–4, in which a tetrode is used. The tetrode screen is maintained at a potential higher than that of the plate. Because of the high screen potential, all the secondary electrons produced at the plate are attracted to the screen. The plate current of the tube is the difference between the primary electrons arriving at the plate and the secondary electrons ejected from the plate.

The current-voltage characteristic of the tetrode of figure 3–4 is illustrated in figure 3–5. As the plate voltage is increased from zero to point *A*, the plate current increases in a normal manner. As the plate voltage is increased to point *A*, the electrons reach the plate with greater and greater

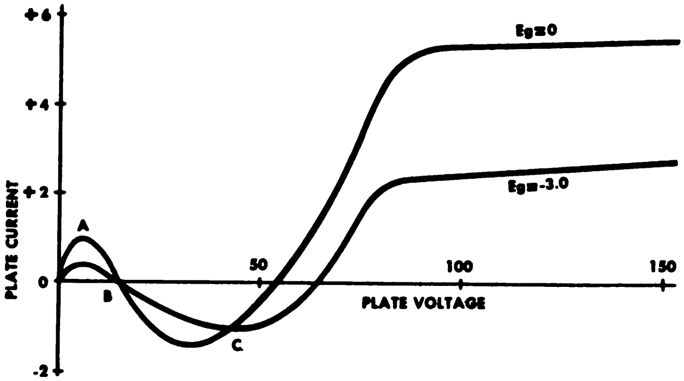


Figure 3–5.—Current-voltage characteristic of a tetrode.

energy, thereby ejecting more and more secondary electrons. Beyond point A the rate of production of secondary electrons increases faster than that of the primary electrons, and the slope of the curve becomes negative. Beyond point B the number of secondary electrons is greater than the number of primary electrons, producing a negative plate current.

The slope of the curve $\frac{\Delta E}{\Delta I}$ at any point is the conductance of the tube at that point. The reciprocal or inverse of the slope is the plate resistance of the tube. The curve has a negative slope from point A to point C, so that the conductance and the resistance of the tube are negative from A to C. A tuned circuit connected with the tube will oscillate if the internal resistance of the tuned circuit equals the negative resistance of the tube and if the tube operates in the negative-resistance portion of its characteristic. The best operating point is the center of the negative-resistance region, that is, near point B.

Operation advantages of the dynatron oscillator:

1. Simple circuit.
2. Frequency range from low audiofrequency to 15 megacycles.
3. Excellent frequency stability; oscillator frequency not affected by changes in operating voltage.
4. Good sine-wave output of low harmonic content.

Disadvantages:

1. Unsuitable for frequencies above 15 megacycles.
2. Low-power output.
3. Dynatron characteristic varies with age of the tube and between tubes of the same type.

TRANSITRON OSCILLATOR

The transitron oscillator, shown in figure 3–6, uses a tube characteristic for obtaining a negative resistance but does not use secondary electron emission to obtain the characteristic. Consequently, the transitron has most of the advantages and a few of the disadvantages of the dynatron. Since the oscillation characteristic is independent of secondary

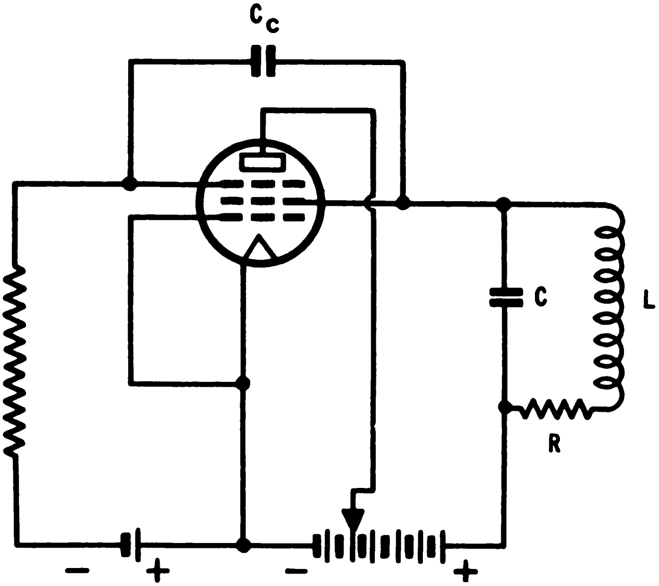


Figure 3–6.—The transitron oscillator.

emission, it remains practically constant throughout the life of the tube.

The action of the transitron is briefly described here. The transitron uses a pentode with the screen grid coupled to the suppressor grid by means of a capacitor. As in the dynatron, the screen is maintained at a potential higher than that of the plate. The suppressor, however, is at a negative potential.

Electrons that pass through the screen grid are repelled by the negative suppressor and return to the screen because of the high potential of the screen. Hence, the suppressor grid produces a "retarding field" and acts as a "virtual cathode" or source of electrons.

The tuned circuit is connected with the screen and is coupled to the suppressor by capacitor *Cc*. A change in voltage in the negative direction at the screen is transmitted to the suppressor through capacitor *Cc*. Since the suppressor is a virtual source of electrons, the negative change in suppressor potential causes the suppressor to repel more electrons to the screen. Thus, the decrease in screen voltage results in an increase in screen current, as shown in figure 3–7. Where the slope of the curve is negative, the screen is the equivalent of a negative resistance. A resonant circuit connected with the screen will oscillate if the screen is adjusted to operate on the negative-resistance portion of its characteristic.

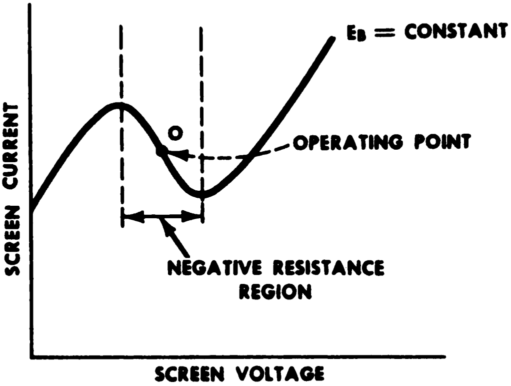


Figure 3–7.—Voltage-current characteristic of the screen grid of a transitron oscillator.

The name transconductance is given to the relation between the current in one element of a tube and the voltage in another element. The action of the transitron depends on a negative transconductance between screen and suppressor grids. Hence, the transitron oscillator is sometimes called a retarding-field negative-transconductance oscillator.

OPERATION

The transitron oscillator, like the dynatron oscillator, is a low-power device. It can generate sinusoidal oscillations in a frequency range from low audiofrequency to 60 megacycles by merely changing the tuned circuit constants. Pentodes suitable for the transitron oscillator are type 57, 58, 59, 6C6, and 6K7.

The frequency stability of the transitron oscillator is comparable to that of a crystal oscillator without temperature control. A change of 33 percent in the screen voltage of a properly designed oscillator alters the frequency only 10 parts in a million (10^6).

Push-Pull Negative-Resistance Oscillators

Two tubes may be connected as in figure 3–8 to produce a negative resistance. The action can be studied by assuming a small positive voltage change on the grid of *V1*. An amplified negative voltage is produced at the plate *A* and is coupled to the grid of *V2*. A larger positive signal is produced at the plate *B*. The larger positive signal is coupled to the grid of *V1*, driving it still further positive. Tube *V1* soon reaches saturation. At saturation, the plate current decreases in V*1* and the action is reversed.

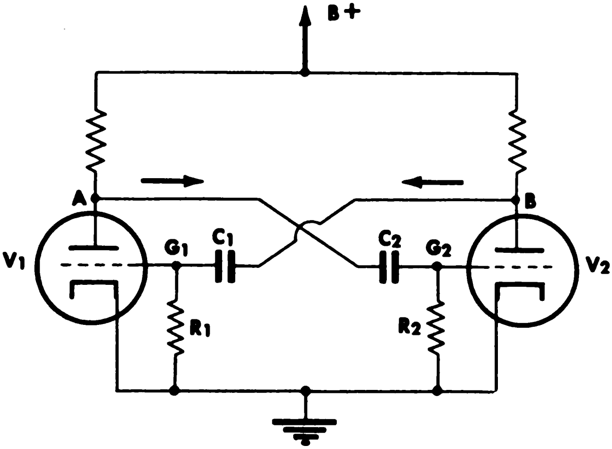


Figure 3–8.—Basic multivibrator circuit.

An effective negative resistance exists between points *A* and *B*. As *A* goes negative in voltage, *B* goes positive by a greater amount, and a decrease in voltage at *A* produces a net increase in voltage between points *A* and *B*. If a resonant circuit is connected between *A* and *B*, as in figure 3–9, a sinusoidal oscillation of low harmonic content and good frequency stability is produced. If no tuned circuit is con-

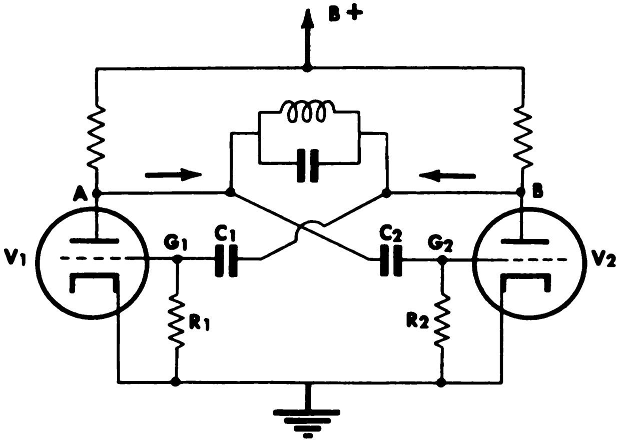


Figure 3–9.—Negative-resistance push-pull oscillator circuit with resonant tank in the plate circuit.

nected between *A* and *B*, the tubes oscillate as a basis multivibrator circuit with each tube alternately driven to cutoff. The amplitude of oscillation is controlled by the grid bias.

VELOCITY-MODULATED TUBES

A velocity-modulated tube is one in which the operation depends upon modulation or change in the speed of electrons passing through it. By means of this change in the speed, the tube produces bunches of electrons separated by space in which there are few electrons.

Operation of Velocity-Modulated Tubes

The first requirement for the operation of velocity-modulated tubes is to produce a stream of electrons, all traveling with the same speed. This is accomplished with an electron gun as shown in figure 3–10. The electrons are emitted from the heated cathode, and are attracted toward the accelerator grid which is maintained at a positive potential with respect to the cathode. Most of the electrons miss the grid wires and pass through the grid to form a beam of electrons all traveling at the same speed.

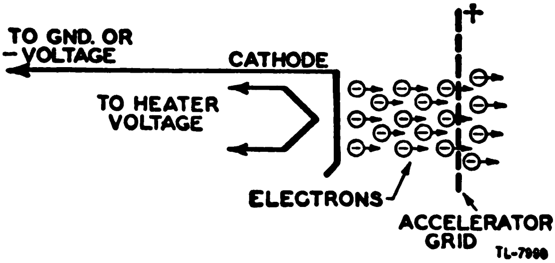


Figure 3-10.—Electron gun.

The beam of electrons is then passed through a pair of closely spaced grids, called buncher grids, each of which is connected to one side of a tuned circuit as shown in figure 3-11. The tuned circuits and the grids are at the same d-c potential as the accelerator grid. The alternating voltage which exists across the tank circuit causes the velocity of the electrons leaving the buncher grids to differ, depending on the time at which they pass through the grids.

The manner in which the buncher produces groups of electrons can best be understood by considering the motion of individual electrons. An electron that passes the center of the buncher at the instant that the alternating voltage is passing through zero leaves the buncher at the same velocity with which it entered. The position that these electrons will occupy when their velocities are plotted against time is shown in figure 3-12 at *A*, *E*, and *A′*. The slopes of the lines in

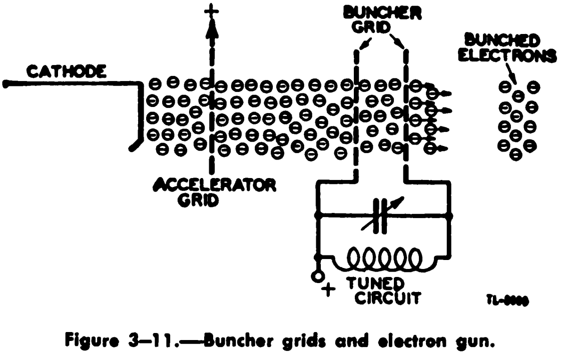


Figure 3-11.—Buncher grids and electron gun.

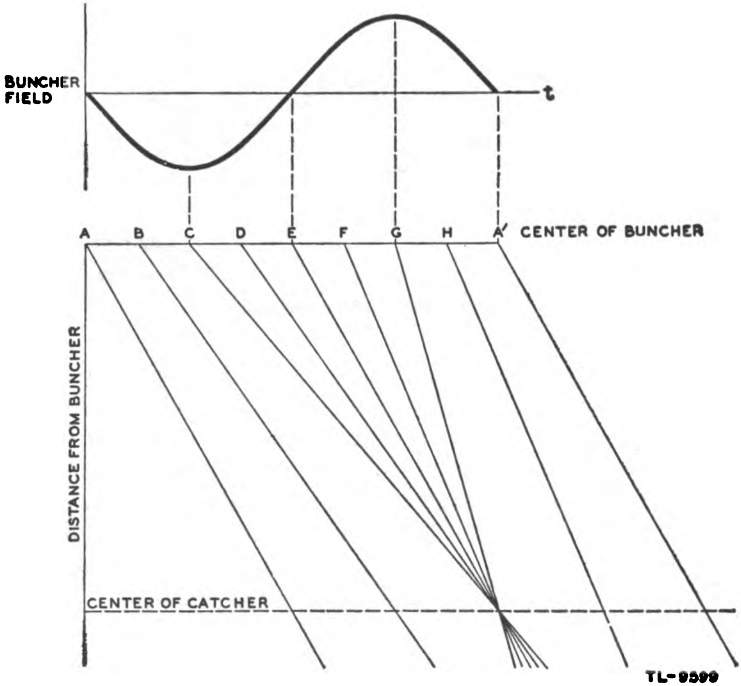


Figure 3–12.—Electron bunching.

figure 3–12 represents the velocities of the electrons. Electrons which pass the center of the buncher a few electrical degrees earlier than the point of zero voltage, as at *C* and *D*, leave with reduced velocity, since the decreased voltage of the buncher slows them up. Electrons that pass a few electrical degrees after the instant of zero voltage, as at *F* and *G*, leave with increased velocity, since the voltage of the buncher is now higher than that of the accelerator grid. If the space beyond the buncher is field-free, the faster electrons, *F* and *G*, will catch up with electron *E* that left with unchanged velocity, and the slower electrons *C* and *D* will lag behind and hence draw near to *E*. At some point beyond the buncher grids, electrons *C*, *D*, *E*, *F*, and *G* will be close together in a group. Another electron, as at *A′*, that leaves the buncher a half-cycle later than *E* has its neighbors draw away. Consequently, the electron stream down the tube consists of bunches of electrons separated by regions in which there are few electrons.

These bunches are allowed to pass through a similar second set of grids, called catcher grids, coupled to another oscillating circuit. If the relative grid potentials are as shown in figure 3–13A, then when each bunch of electrons reaches the first grid of this set, the field is such that it slows down the electrons and thus absorbs energy from them. By the time the bunch of electrons reaches the second grid of the set, the relative grid potentials are reversed, as shown in figure 3–13B, because it takes the group of electrons approximately a half-cycle to go from one grid to the other. Therefore, the second catcher grid also slows down the electrons, absorbing more energy from the electrons. Thus, in delivering energy to the tuned circuit connected to the catcher grids, the speed of the electrons is greatly reduced. After passing this second set of grids the spent electrons are removed from the circuit by a positive collector plate.

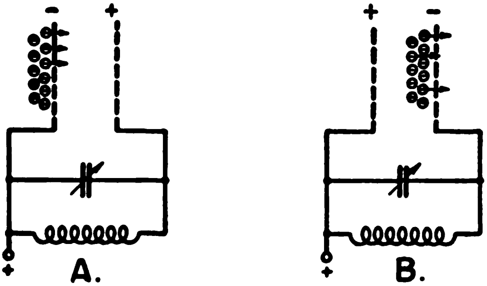


Figure 3–13.—Charge of catcher-grid polarity with oscillation.

KLYSTRON

A vacuum tube containing the electron gun, grids, and the positive collector plate just described is called a klystron. An early reflex velocity-modulated oscillator tube of the internal-cavity type is the Western Electric 723A/B. This tube was superseded by the 2K25, which has a greater frequency range and several refinements in design. Figure 3–14 shows a cross-sectional view of the 2K25 reflex oscillator. The resonant cavity is formed in part by the volume included between the frame which supports the cavity grids and also by the volume between the flexible vacuum diaphragm and one of the frames. This diaphragm also supports a vacuum housing containing the repeller. The electron optical system consists of a disc cathode, a beam electrode, and an accelerating grid. These are designed to produce a slightly convergent outgoing electron stream. The purpose of this initial convergence is (1) to offset the divergence of the stream caused by space charge after the stream passes the accelerating grid, and (2) to minimize the fraction of the electron stream captured on the grid frame on the round trip. The repeller is designed to provide a nearly uniform retarding field through the stream cross section.

Power is extracted from the resonant circuit by the loop coupling and is carried by the coaxial line to the external circuit. The center conductor of the coaxial line is supported by a polystyrene insulator and extends beyond the outer conductor to form a probe through a hole in that wall of the waveguide which is perpendicular to the *E* lines so that the full length of the probe extends into the guide. The outer conductor is connected to the waveguide either metallically or by means of an r-f choke circuit.

The klystron tube employs a standard octal base modified to pass the coaxial line. Thus, if a standard octal socket is similarly modified and mounted on the waveguide, it is possible to couple the oscillator to the waveguide and to the power-supply circuit simply by plugging it into the socket, just as with any conventional tube. Tuning this type of oscillator is a serious problem. This will be appreciated when it is realized that the tuning mechanism must set frequencies to within 1 megacycle in a device in which the frequency changes at the rate of approximately 200 megacycles per thousandth of an inch displacement of the grids. In other words, the tuner is required to adjust the grid spacing to an accuracy of five-millionth of an inch. The operation of the tuner is seen from an examination of the cross section as shown in figure 3–14. On one side of the tube a strut acts as a rigid vertical support and provides a hinge for lateral

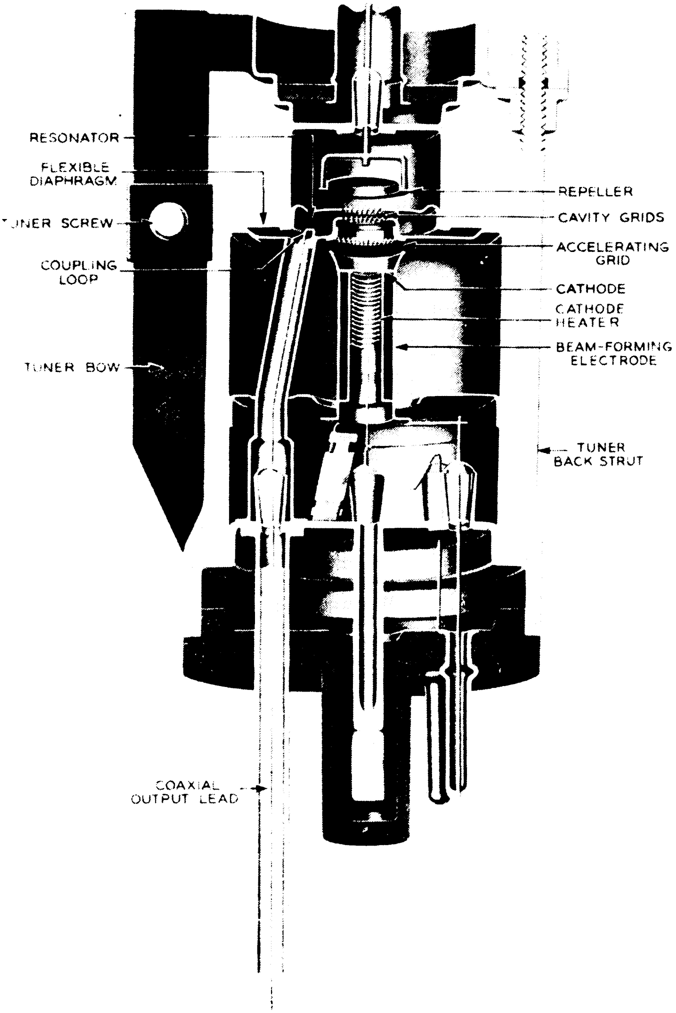


Figure 3–14.—A 3-centimeter reflex oscillator with an internal resonator.

motion. On the opposite side the support is provided by a pair of steel strips. These are clamped together where they are attached to the vacuum housing support and also where they are attached to a short fixed strut near the base. A nut is attached rigidly to the center of each strip. One nut has a right-handed and the other a left-handed thread. A screw that is threaded right-handed on one half and left-handed on the other half of its length turns these nuts and drives them apart. Thus, the mechanism is a toggle which, through the linkage provided by the repeller housing, moves the grids relative to one another and provides tuning action.

For use as the local-oscillator tube in a radar receiver a klystron need not supply large amounts of power, but should oscillate at a frequency that is stable and easily controlled. Output power in excess of 20 mw is available from most reflex klystrons, and this power is sufficiently greater than the power required by a mixer crystal to permit use of loose coupling and therefore prevent loss of signal power to the oscillator.

MAGNETRONS

Magnetron oscillators for generation of ultra-high frequencies are classified as electronic and negative-resistance oscillators.

An electronic magnetron operates by reason of the electron transit-time characteristic of a vacuum tube; that is, the time electrons take to travel from the cathode to the plate. This oscillator is capable of generating very large peak-power outputs at frequencies in the thousands of megacycles. Although its average output is small, it is especially well adapted for pulse-type operation.

A negative-resistance magnetron operates by reason of a static negative resistance between its electrodes and has a frequency equal to the natural period of the tuned circuit connected to the tube. Magnetrons employed in radar transmitters are often called resonant-cavity magnetrons. Radar magnetrons have the basic form of a cylindrical diode, the magnetic field being applied in a direction parallel to the

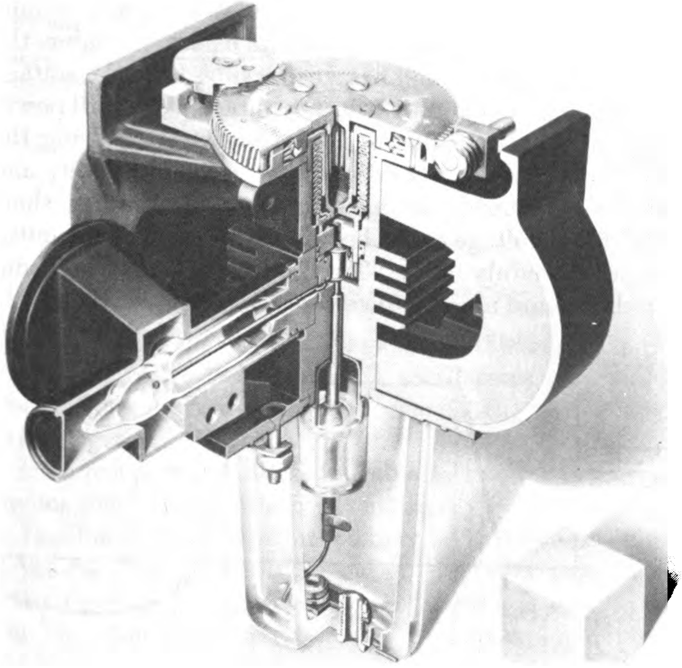


Figure 3–15.—A view of a sectional 2J51, tunable, "packaged" magnetron.

axis of the cathode and anode cylinders. The anode is made from a copper block and its internal surface is separated into a number of segments by holes in the block that function as cavity resonators. Because radar magnetrons must produce power in short pulses of tremendous amplitude, the tubes are designed for high voltage and high cathode emission. Figure 3–15 shows a 2J51 tunable PACKAGED magnetron which has been cut away to show the internal structure. This magnetron is tunable in the *X* band between 8,500 and 9,600 mc.

Operation and Care of Magnetrons

When the magnetron is operating properly, the anode-voltage pulse is related to the magnetron-current pulse and to the r-f output-voltage pulse in the manner shown in figure 3–16. Because the magnetron current becomes appreciable only when the anode voltage is near its maximum value, the current pulse is shorter and has steeper sides than the voltage pulse. During the flat top of the r-f voltage pulse, full power is produced at essentially constant frequency. During the steeply sloping sides, operation is at reduced power, and appreciable frequency changes are noted. In the short periods of low voltage at the beginning and end of the pulse, the output is mainly noise. The leading edge of the modulator pulse should not rise too steeply. An excessively rapid

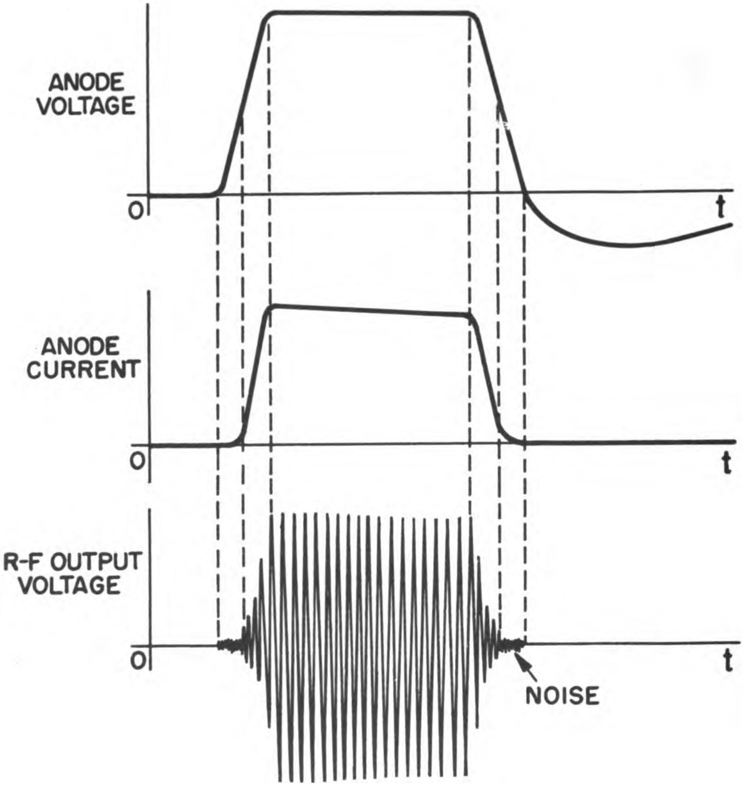


Figure 3–16.—Pulse shapes of magnetron anodevoltage, anodecurrent, and r-f output voltage.

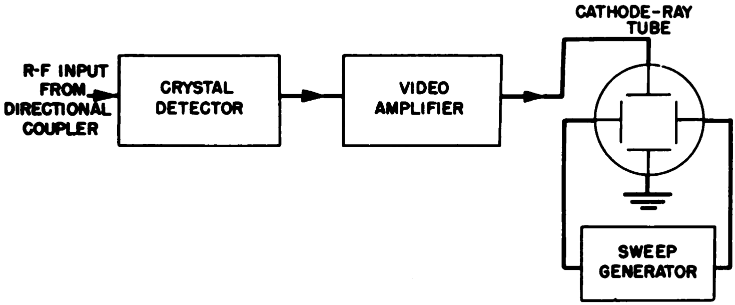
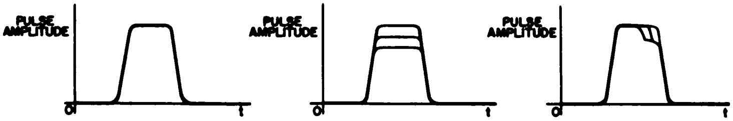


Figure 3–17.—Block diagram of an r-f envelope indicator.

rise may cause the anode voltage to pass through the proper operating range before π-mode oscillations can build up. Oscillations may subsequently occur in the wrong mode or fail altogether.

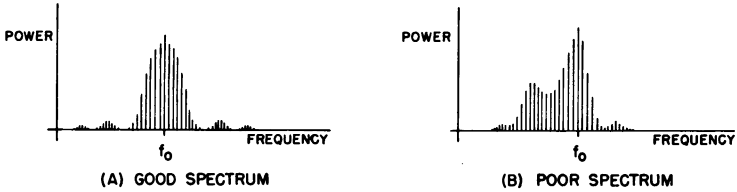
During operation, it is desirable to know whether or not the magnetron is oscillating consistently in the π-mode. An indication of the performance may be had by observing the envelope of the r-f voltage pulse. In order to observe the pulse envelope, a small amount of power is diverted from the r-f transmission system to an r-f envelope indicator. Shown in block diagram form in figure 3–17 are a crystal detector, a video amplifier, and a cathode-ray tube. The r-f pulses are rectified by the detector, and the resulting video pulses after amplification are displayed on the cathode-ray-tube screen. The sweep generator is synchronized with the modulator pulses. A proper operating magnetron has an r-f pulse envelope similar to that of figure 3–18A. If mode skipping or frequency splitting is taking place, the envelope has the appearance of figure 3–18B. Mode splitting produces the envelope of figure 3–18C.



(A) NORMAL ENVELOPE (B) ENVELOPE SHOWING MODE SKIPPING (C) ENVELOPE SHOWING MODE SPLITTING

Figure 3–18.—Examples of r-f pulse envelopes.

Another way of evaluating magnetron performance conveniently is through observation of the frequency spectrum of the r-f pulse. For proper radar-set operation the power in the r-f pulse should be concentrated in frequencies within the bandwidth of the receiver. Power contained in frequency components lying outside the receiver bandwidth is wasted. Examples of good and bad spectra are given in figure 3–19. Note that in a good spectrum most of the power is confined to a frequency band centered at the frequency f_0. In the poor spectrum the power is distributed over a much wider band, and consequently some of the echo power may not pass through the receiver. One reason for a poor spectrum is that the anode-voltage pulse may not have proper amplitude to ensure operation in the π-mode. Another is that the r-f line connected to the magnetron may be appreciably mismatched to the load, thus giving rise to severe frequency pulling. A poor spectrum may also result from use of a magnet of improper strength. The electrons in the interaction space are then unable to rotate in synchronism with the π-mode field. The spectrum may be determined by means of an echo box or spectrum analyzer.



(A) GOOD SPECTRUM (B) POOR SPECTRUM

Figure 3–19.—Examples of magnetron spectra.

When a magnetron is being used for the first time, the pulse voltage should be increased gradually. This is especially important if the magnetrons are pulsed by power-amplifier modulators where the charge on the storage capacitor is much larger than is normally allowed to pass through the magnetron in one pulse. The magnets used with magnetrons are made of highly retentive alloys.

In nonpackaged assemblies the magnets are provided with keepers which should be inserted in the air space when the magnets are not in use. During operation the magnetron replaces the keeper, and under these conditions it is important not to jar the magnet or strike it with ferromagnetic material, since treatment may cause a marked decrease in the field strength.

CRYSTALS

Microwave radar receivers employ crystal mixers to change the r-f input signal to an i-f signal which is then amplified by vacuum tubes.

The nonlinear properties of crystal detectors are due to a surface-contact phenomenon between a metal conductor and the crystal. The surface phenomenon is similar to that of varistors and thermocouples. The metal conductor, called a catwhisker, is sharpened and made to touch the crystal at one spot as illustrated in figure 3–20. The whisker contact is experimentally adjusted for correct forward and back resistances. As in the thermocouple, electrons move more easily in one direction across the point of contact between the metal and the crystal. The result is a voltage-current characteristic, as illustrated in figure 3–21.

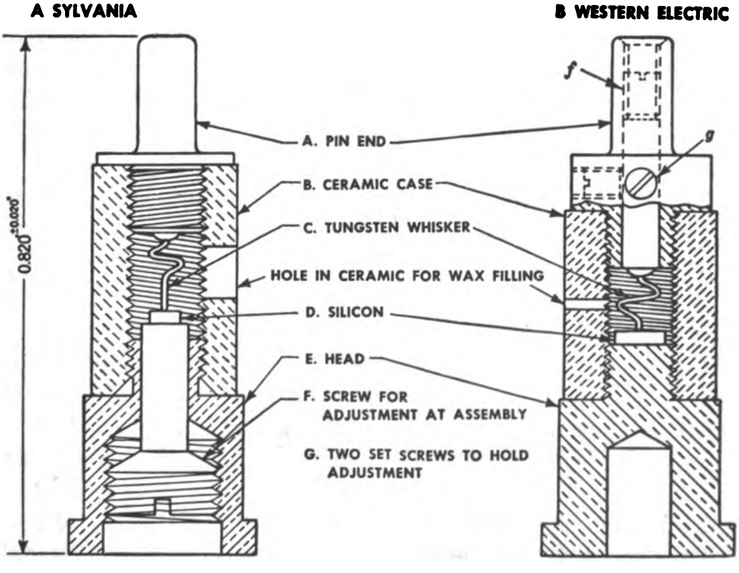
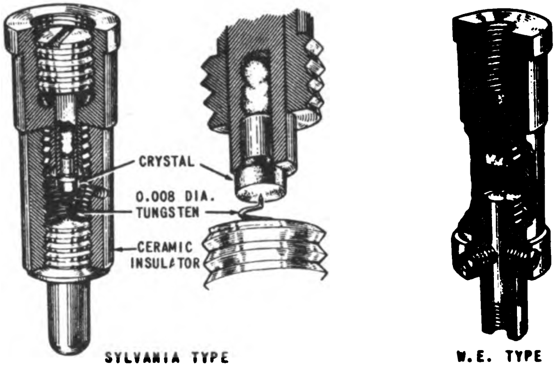
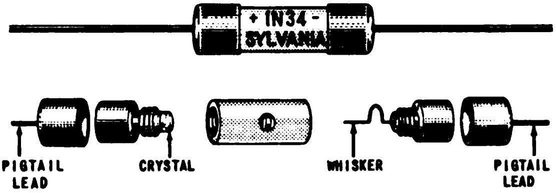


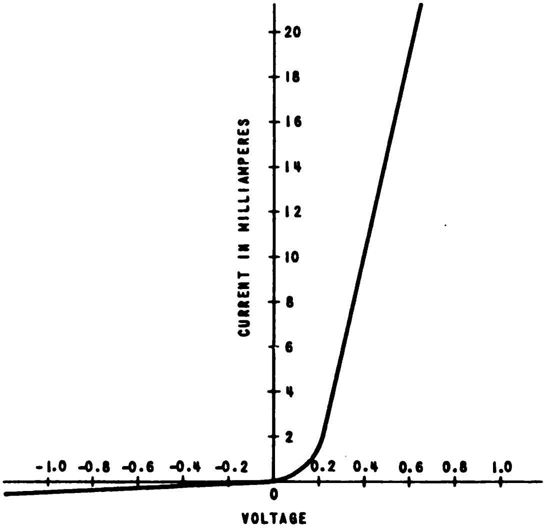
Figure 3–20.—Ceramic cartridges.



CARTRIDGE TYPES



PIG-TAIL TYPE



VOLTAGE - CURRENT CHARACTERISTIC

Figure 3–21.—Construction details of crystal detectors of the cartridge and pig-tail type, and the voltage-current characteristic of a tungsten-silicon detector.

The effectiveness of a detector is usually expressed in terms of the ratio of the reverse, or back, resistance to the forward resistance. The perfect detector would have an infinite back-resistance and a zero forward-resistance, resulting in an infinite ratio of back to forward resistance.

The operation of the crystal as a mixer is similar to that of the diode. As with the diode, the crystal operates as a linear detector and the i-f voltage is linearly dependent on the signal amplitude, particularly since the signals are small compared with the local-oscillator power. Transit-time effects are minimized because of the small physical size of the point contact in the crystal at which rectification takes place. Even in the microwave region, transit-time effects may be neglected for most purposes. The overall noise figure of the present-day crystal is better than that of vacuum tubes now available.

MICROWAVE DUPLEXERS

In order to use an antenna for both transmission and reception, some sort of switch must be used. The time constants required of the circuits eliminate the possibility of any mechanical switch. A radar duplexer is the microwave equivalent of a low-loss, double-pole, double-throw switch. The requirements for a radar duplexing switch are as follows:

1. During transmission the switch must connect the antenna to the transmitter and at the same time disconnect the antenna from the receiver. Also, the switch must isolate the receiver from the transmitter to protect the sensitive elements of the receiver.
2. In order to see close targets, the switch must rapidly disconnect the transmitter and connect the receiver to the antenna immediately after transmission.
3. During reception the transmitter must be isolated from the incoming signals.
4. The switch must absorb little power.

TR and ATR tubes are known as electronic switches. The TR tube is located between the main waveguide and the receiver input circuit, and disconnects the receiver from the rest of the r-f system during the time the transmitter is in operation. The TR tube consists of a re-entrant cavity having two points of entry—one to the main waveguide and the other to the coaxial line of the receiver input circuit. Coupling at the points of entry is provided by apertures. The re-entrant portion of the cavity is formed by two closely spaced conical-shaped electrodes, which constitute a spark gap that breaks down in the presence of the high voltage of the transmitted pulse.

Because breakdown of the gap prevents buildup of oscillations in the cavity, very litle coupling is provided between the two points of entry, and, as a result, very little transmitted power is able to reach the receiver. Echo signals from targets are able to pass through the cavity, however, because these signals are too weak to cause ionization of the TR spark gap. Oscillations therefore build up in the TR cavity, and echo power is coupled through the cavity to the receiver with negligible loss.

Because power in the echo signals is extremely small (of the order of $1\mu w$), it is very important that as much of the echo power as possible be directed to the receiver, and that very little of it be directed to the transmitter. An ATR tube or device is used for this purpose, and is connected at a point between the transmitter and the TR tube. It is similar in construction to the TR tube, except that only one point of entry is provided. The ATR device serves as a switch to disconnect the transmitter from the rest of the r-f system except while the pulse is being transmitted.

During the reception of echo signals, the ATR cavity constitutes a high-Q parallel resonant circuit at the side wall of the guide. The high impedance at the side wall provides essentially a short-circuit termination across the guide for waves traveling along the guide. The short circuit in the direction of the transmitter at the ATR location is made to appear as an open circuit at the location of the TR device by spacing the two devices an odd-integral number of quarter wavelengths apart. Thus, during the reception of echo signals, the signal path is in the direction of the receiver at the TR device. The ATR device does not interfere with the propagation of transmitter pulses through the waveguide because, during a transmitted pulse, the ATR spark gap ionizes and causes the cavity to appear as a low impedance at the spark gap. The cavity thus has the effect of closing the coupling aperture during the transmitted pulse.

QUIZ

1. The effectiveness of a crystal detector is usually expressed in terms of the
   a. slopes of the characteristic curve in the nonconducting and conducting regions.
   b. type of crystal used.
   c. ratio of the forward to the back resistance of the crystal.
   d. current-voltage ratio.

2. The crystal has replaced the vacuum tube detector in high-frequency application because the crystal
   a. requires no *A* supply.
   b. can carry r-f current.
   c. has lower shunt capacitance.
   d. oscillates easily.

3. The process of reinforcing an input signal voltage of a vacuum tube by the addition of an in-phase portion of its input voltage is known as
   a. demodulation.
   b. modulation.
   c. regeneration.
   d. degeneration.

4. Negative feedback in an amplifier tube has the advantage of improving the output voltage wave form by
   a. reducing distortion introduced within the tube.
   b. canceling out the noise voltage produced in the preceding stages.
   c. reducing amplitude distortion caused by the flow of grid current in the tube.
   d. the same method as positive feedback.

5. The gain of an amplifier using negative feedback is
   a. less than that of an amplifier without negative feedback.
   b. independent of the feedback factor.
   c. proportional to the frequency of the signal.
   d. always independent of the gain of the amplifier without feedback.

6. Negative feedback is NOT provided by
   a. a resistor and capacitor in series between the plate of one stage and the plate of the preceding stage.
   b. a resistor and capacitor in series between the plate and the grid of the same stage.
   c. a bypassed cathode resistor in the plate circuit.
   d. an unbypassed cathode resistor in the plate circuit.

7. To obtain large power output over a maximum frequency range, a 2-tube oscillator is operated
   a. in cascade.
   b. in push-pull.
   c. in parallel.
   d. as a tuned-plate tuned-grid oscillator.

8. The screen grid in a transitron oscillator is a negative resistance because as the
   a. plate current decreases the screen current decreases.
   b. screen voltage increases the screen current decreases.
   c. screen voltage decreases the output decreases.
   d. screen voltage increases the screen current increases.

9. The output of a transitron is taken from the
   a. screen circuit.
   b. cathode circuit.
   c. grid circuit.
   d. plate circuit.

10. In a dynatron oscillator the screen
    a. contains the resonant circuit.
    b. is coupled to the suppressor grid.
    c. is the negative-resistance element.
    d. has a potential greater than that of the plate.

11. The negative resistance produced in the dynatron oscillator is a result of
    a. plate-current saturation.
    b. screen-grid suppressor-grid coupling.
    c. regenerative feedback.
    d. secondary emission.

True—False

12. In order to produce sustained oscillations, a signal must be fed back to the grid circuit out of phase with the input signal.

13. The transitron oscillator uses secondary emission to produce a negative resistance.

14. The feedback necessary to maintain oscillation may take place through the grid-plate interelectrode capacitance.

15. The transitron oscillator is more stable than the dynatron oscillator throughout the life of the tube.

CHAPTER 4

ANTENNAS

The characteristics and operation of any radar antenna system affects the performance of the radar equipment in several ways. The two most important ways pertain to the operation of the antenna as a directional radiator or absorber of radio frequency and to the behavior of the antenna as a circuit element which has to be matched to its associated transmission line.

The directional features of radar antennas are usually their most important characteristic. A directive transmitting antenna makes it possible to illuminate only certain selected targets at any one time, and a directive receiving antenna makes it possible for the radar set to look only in selected directions at a given time.

ANTENNA FEEDS

The radiation pattern of the antenna feed must be directive with the major portion of the energy radiated toward the reflector. The theorical design of a reflector on a lens is based generally on the assumption that the feed is a point source. Deviations of the feed from a point-source radiator result in phase errors over the aperture of the antenna.

FEEDS FOR PARABOLOIDS

An antenna that produces a sharply directive pattern and a uniphase wavefront can be constructed by illuminating a reflected paraboloid with a properly designed feed placed at its focus.

The feed for a paraboloid should (1) be mechanically appropriate, (2) provide impedance match to the feedline, (3) have a uniphase characteristic, (4) have an amplitude characteristic such that the feed has a major radiation lobe which strikes the center of the reflector, decreases its intensity smoothly to a value about 8 to 10 db below the maximum in the direction of the reflector to boundaries, and is small for all directions that do not strike the reflector, (5) have a polarization characteristic such that the electric vectors in the reflected wavefront are all polarized in the same direction and, (6) be small so that it does not disturb the radiation characteristics of the antenna as a whole.

The shadow effect of the feed, the feedline, and the necessary mechanical supports of the antenna should be small or absent. Primary radiation that does not strike the reflector, or reflected energy that strikes the feed or associated structure and is then reradiated, must be sufficiently small or so controlled that the antenna pattern is not distorted.

The feed for paraboloid reflector should be a small directive antenna. A simple dipole or half-wave doublet can be used to feed a paraboloid. However, the dipole is not very efficient because of inadequate directivity. It is preferable and more common to use a dipole array in which one doublet is excited directly and in which another doublet, or a reflecting surface, is excited parasitically.

Dipole feeds, although useful in practice, have poor polarization characteristics. Since waveguide transmission lines are common in the microwave radar bands, waveguide feeds are preferred in most paraboloidal antennas.

If a single open-ended waveguide or electromagnetic horn is used to feed a section of a paraboloid that includes the vertex, the waveguide feedline partially blocks the reflected wave and causes a shadow, or interference zone. To avoid this difficulty several rear waveguide feeds have been used. In this type of feed the waveguide passes through the vertex of the paraboloid and supports the feed at the focus. The energy can be caused to radiate back toward the reflector in any one of several ways, some of which involve reflecting rings, reflecting plates, or parasitically excited doublets.

The Cutler feed is one of the most successful and most common rear feeds. It operates by radiating the energy back toward the paraboloid through two apertures. These apertures are shown in figure 4–1.

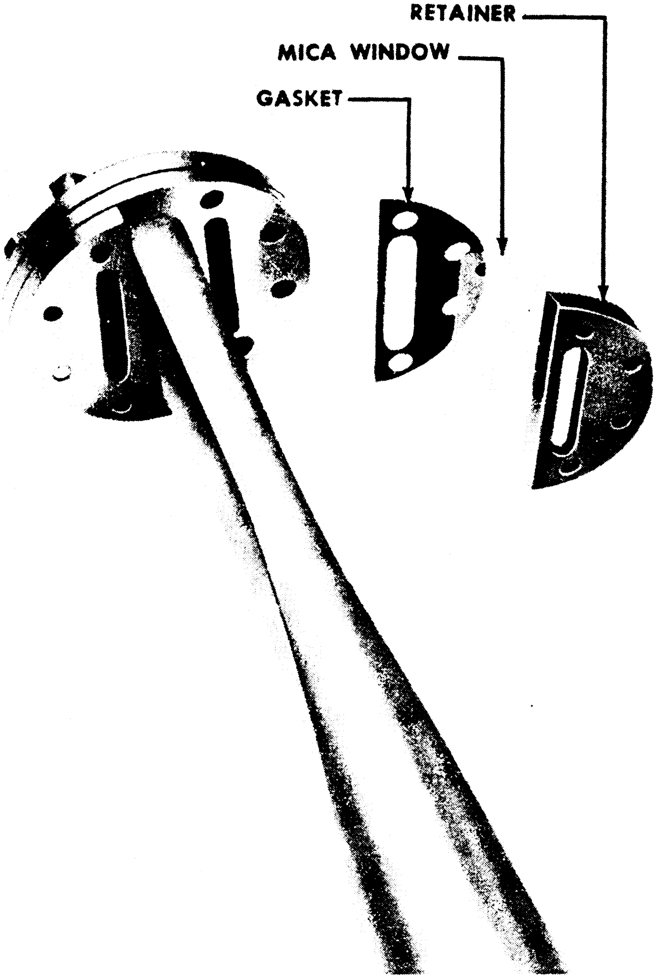


Figure 4–1.—Dual aperture rear feed horn (Culter).

PARABOLIC REFLECTORS

Most radar antennas employ reflectors to focus beams of microwave energy. The reflectors have special shapes to produce special patterns. If they are parabolic they may be paraboloids that focus in both directions, or they may be parabolic cylinders that focus in only one direction. Paraboloids are illuminated by a point source. Parabolic cylinders are illuminated by a line source.

Paraboloidal and parabolic-cylinder antennas may be compared as follows: paraboloidal antennas are (1) simpler in design, (2) usually lighter, (3) more efficient, (4) have better patterns in the desired polarization, and (5) are more appropriate for conical lobing or spiral scanning. Antennas employing parabolic cylinders are (1) simpler mechanically, since only singly curved surfaces are required, and (2) have separate electrical control in two perpendicular directions. This last advantage of parabolic cylinders is important in special antennas where very large aspect-ratios are desired.

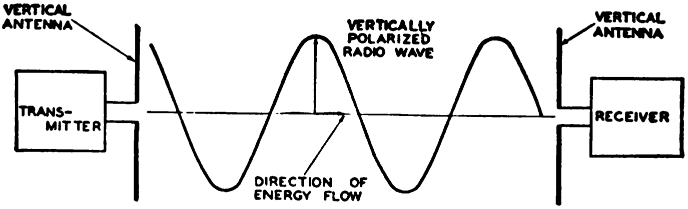
RADIATION-RESISTANCE

An antenna must radiate as much energy as possible in the form of an electromagnetic wave. It is common practice to use a fictitious "resistance," called radiation-resistance, to measure the amount of radio power sent out from the antenna. All other factors being the same, the greater the radiation-resistance, the better the antenna. The value for a half-wave antenna in free space, measured at the current maximum which is the center of the antenna, is approximately 73.3 ohms. For a quarter-wave antenna measured at its current maximum the radiation-resistance is approximately 36.6 ohms.

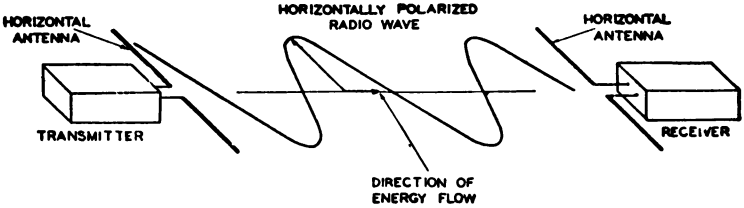
WAVE POLARIZATION

The position of an antenna in space determines the polarization of the emitted wave. Thus, an antenna which is vertical with respect to the earth radiates a vertically polarized wave, while a horizontal antenna radiates a horizontally polarized wave. Figure 4–2 shows the vertical electric field of a vertical antenna and the horizontal electric field of a horizontal antenna.

For low frequencies this polarization continues to be the same while the radiated field travels through space. At high frequencies, however, the polarization usually varies, sometimes quite rapidly, because the wave splits into several components that follow different paths. These paths will not be the same length; therefore, in general, the recombined electric vectors will not be parallel. If this is the case, the path traced by the point of the resultant vector will be circular or elliptical, and such a field is known as either a circularly or elliptically polarized field.



A. VERTICAL TRANSMITTING ANTENNA PRODUCING VERTICALLY POLARIZED ELECTRIC WAVES WHICH ARE RECEIVED ON VERTICAL RECEIVING ANTENNA



B. HORIZONTAL TRANSMITTING ANTENNA PRODUCING HORIZONTALLY POLARIZED ELECTRIC WAVES WHICH ARE RECEIVED ON HORIZONTAL RECEIVING ANTENNA

Figure 4–2.—Vertical and horizontal polarization.

FIELD STRENGTH

Field strength, which refers to the value of the electric field at a given point, is measured in terms of volts per meter (one meter=3.28 feet). One volt per meter is equivalent to a potential of 1 volt induced in an antenna wire 1 meter long. Since a volt per meter is too large a unit for most practical considerations, millivolts per meter and microvolts per meter are used more frequently. For example, if 50 microvolts are generated between the ends of a conductor 1 meter long when a radiated wave cuts across it, the field strength is 50 microvolts per meter or $50 \mu v/m$.

LOBING

Microwave radar, with its narrow beam, is an excellent instrument for finding the coordinates of a target. In finding these coordinates the two properties which deserve particular attention are the accuracy and rate with which the coordinates of a target can be measured.

A lobing antenna that is to provide information concerning one coordinate only produces two beams, one at a time, and switches rapidly from one to the other. This process is

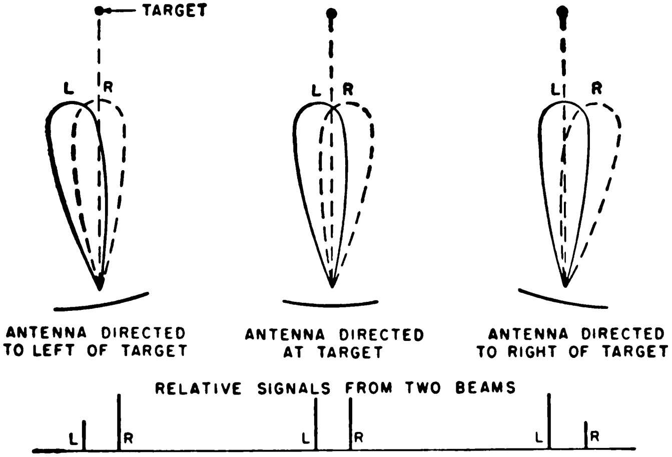

TARGET
L
R
L
R
L
R
ANTENNA DIRECTED TO LEFT OF TARGET
ANTENNA DIRECTED AT TARGET
ANTENNA DIRECTED TO RIGHT OF TARGET
RELATIVE SIGNALS FROM TWO BEAMS
L
R
L
R
L
R

Figure 4–3.—Lobe switching.

called lobe switching. The two beams are nearly coincident, differing in direction by about one beam width. Signals are received as each beam strikes the target. When the signals from the two beams are compared, they are equal only if the target lies on the bisector between the beams as shown in figure 4–3.

The two signals can be compared visually on an indicator screen of the radar, or they can be compared electrically and fed directly into circuits that control the direction of fire.

When both elevation and azimuth are to be determined, four discrete beams are used. Radar antennas designed for solid angle coverage commonly produce a single beam, which rotates rapidly and continuously around a small cone. This scan is known as a conical scan as shown in figure 4–4. The comparison of the amplitude in a vertical plane can be used to give the elevation of the target, and a similar comparison in a horizontal plane can be used to give its azimuth.

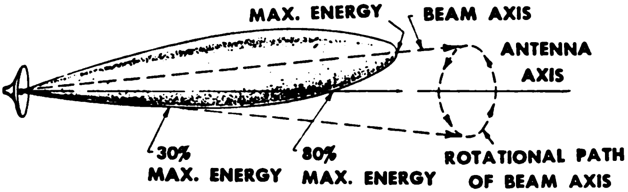


Figure 4–4.—Antenna beam with conical scan.

Conical Scanning

A conical-lobing antenna produces a beam that nutates rapidly about a fixed axial direction; that is, the axis of the r-f beam is rotated so that it generates a cone, the vertex of which is the antenna. The conical scan is accomplished by the motion of the feed. If the feed is moved so that the polarity of the beam does not change, the motion is called nutation. Most scans are done by nutating feeds. Sometimes the feed nutates in a small circle around the focus of the paraboloid, and sometimes it nutates up and down, left and right, or in both directions alternately.

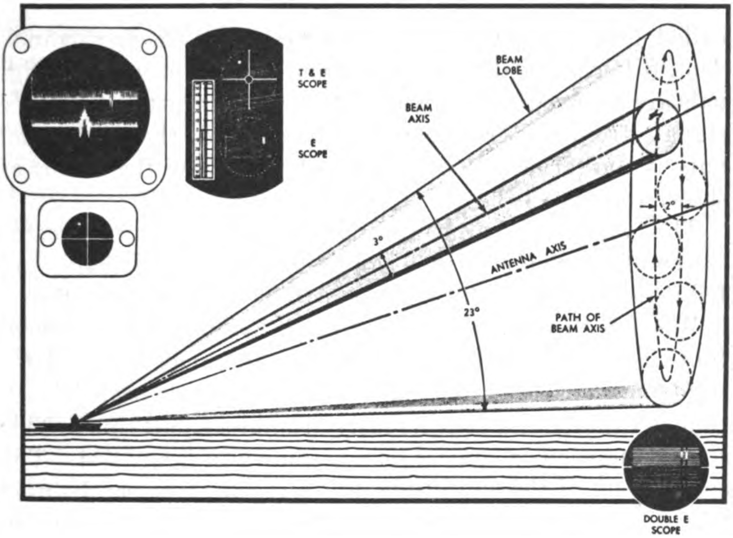


Figure 4–5.—Elliptical scan.

Elliptical Scanning

In elliptical scanning the antenna feed moves in an ellipse and causes the beam to shift 10° in a vertical direction and 1° in a horizontal direction describing an elliptical path in space. The total area covered by the beam is 23° high and 5° wide as shown in figure 4–5.

NUTATION

Any scan is said to be nutated if the polarization of the beam is not changed during the scanning cycle. This means that the axis of the moving feed must not change horizontal or vertical orientation while the feed is moving.

RADAR ANTENNA ASSEMBLY

The following is a description of a complete, typical radar antenna. The antenna drive motor has a hollow shaft and is used to drive the antenna feedline. It is a 440-volt, 60-cycle, 3-phase, $\frac{1}{12}$-horsepower induction motor. It is totally enclosed in a waterproofed housing and runs at approximately 1,750 r. p. m. The a-c supply for the drive motor is connected through a contactor in the controller. The contactor holds the supply closed except when the overload relay operates because of overload and releases the contactor.

The sine-wave generator consists of a hollow, square, stator structure upon which are wound four coils. The coils are connected to provide two voltages, which are equal in value and 90° apart in phase. A permanent-magnet rotor is mounted on an extension of the motor shaft. The nominal speed of the generator is 1,750 r. p. m. It generates a 29-cycle-per-second, two-phase, 16-volt signal. The output is used to provide a reference for angular pointing-information.

The r-f energy of the transmitter is conducted by a rectangular waveguide through an entrance hole in the housing of the antenna drive motor. From there it is conducted by the waveguide to the antenna. To provide a waveguide of circular cross-section through the motor, the entrance hole is connected to a waveguide taper-transformer. This matches the rectangular waveguide to the circular waveguide in the motor. The taper-transformer is pretuned and ends at a "wobble" joint at the rear and on the axis of the motor. The wobble joint permits the circular waveguide section to be nutated. The nutating portion of the waveguide fits through the hollow motor shaft and is fixed in position by a front bearing and a rear pivot bearing.

The feedline end of the waveguide section is supported by the keyed ball bearing at the front of the motor. In operation, the radiating end describes a circle of 0.36-inch diameter about the axis of the paraboloid. The front support bearing is mounted eccentrically with respect to the motor rotor and causes the feedline to be driven with a conical motion. The entire mechanism is dynamically balanced. The waveguide again converts a circular to a rectangular cross section between the eccentric bearing and the feedline.

The energy is transmitted to the end of the guide, where it branches into the two U-shaped turns and leaves the guide through two narrow windows. The energy is concentrated into a narrow beam by the paraboloid reflector. A factoryset screw gives proper impedance matching. The reflector has an opening to allow the guide to be moved. To prevent the r-f energy that passes through this opening from burning out the motor bearings, a multiple-groove disc is placed behind the reflector. The grooves are quarter-wave chokes that suppress transmission of the energy that would otherwise reach the motor.

The paraboloid reflector is 30 inches in diameter and has a focal length of 10.6 inches. The window at the end of the guide must be accurately aligned with the rectangular waveguide connected to the motor housing.

The antenna has a gain of about 33 db. The beam width is about 3.1° and shifts 1.5°. Minor lobes are about 25 db down (one-way transmission) and have a negligible effect upon reception.

SUMMARY

The function of the antenna system is to take the energy from the transmitter, radiate it in a directional beam, pick up the returning echo, and pass it to the receiver with a minimum of losses. The antenna system may be considered to include the transmission lines from the transmitter to the antenna array, the antenna array itself, the transmission line from the antenna array to the receiver, and any antenna switching devices and receiver-protective devices which may be present.

QUIZ

1. Which type of radar antenna feed radiates energy back to the paraboloidal reflector through two apertures?
    a. Dipole.
    b. Waveguide horn.
    c. Cutler.
    d. Waveguide terminating in a dipole.

2. Which of the following is an advantage of parabolic-cylinder antennas over paraboloidal antennas?
    a. They are more appropriate for conical lobing.
    b. They are simpler mechanically.
    c. They have better patterns in the desired polarization.
    d. They are usually lighter.

3. A center-fed half-wave antenna has an input resistance of approximately
    a. 36.6 ohms.
    b. 73 ohms.
    c. 300 ohms.
    d. 146 ohms.

True—False

4. The radiation pattern of an antenna feed must be directive, with the major portion of the energy radiated away from the reflector.
5. The feed for a paraboloid should provide an impedance match to the feedline.
6. An antenna which is vertical with respect to the earth radiates a horizontally polarized wave.
7. A conical-lobing antenna produces a beam that nutates rapidly about a fixed axial direction.
8. A lobing antenna provides information concerning one coordinate only, but produces two beams, one at a time, and switches rapidly from one to the other.
9. The position of the antenna in space determines the polarization of the emitted wave.
10. Waveguide feeds are preferred in most paraboloidal antennas since waveguide transmission lines are common in microwave radar bands.

CHAPTER 5

TRANSMITTERS

In this discussion the term TRANSMITTER refers to the magnetron and the pulse-transformer that drives the magnetron. A high-voltage pulse from a modulator causes the magnetron to oscillate for the duration of the pulse. The transmitter output is an r-f pulse containing oscillations at the frequency for which the magnetron was designed or tuned. The repetition rate of these pulses is established at the timing generator. Either waveguide or coaxial transmission lines connect the transmitter to the antenna, TR box, ATR box, and AFC mixer.

SELF-PULSED SYSTEM

In the self-pulsing radar transmitter the functions of transmitting and timing are carried out by one component. This type of transmitter in effect oscillates at two frequencies: the CARRIER FREQUENCY, as determined by the L–C constants of the tank circuit, and the PULSING FREQUENCY, as determined by the R–C constants of the grid circuit. The grid capacitor largely controls the width of the pulse in that its size determines the number of positive r-f swings required to charge it sufficiently to block the tube. The grid-leak resistor controls the pulse repetition frequency to the extent that it determines the time required for sufficient charge to leak out of the grid capacitor to unblock the tube. The timing pulse for other components is developed across a resistor in the cathode circuit of the blocking oscillator.

EXTERNALLY-PULSED SYSTEM

In the externally-pulsed type of radar transmitter the function of the r-f oscillator is relatively simple, that is, to generate powerful pulses of r-f energy at regular intervals. As the resting time is very long compared to the transmitting time, the oscillator may be greatly overloaded during transmission to increase the peak power. In this type of operation the r-f oscillator requires power in the form of a properly timed, high-amplitude, rectangular pulse. In most cases the timing oscillator cannot fulfill this requirement directly, and therefore it is necessary to use a driver and a modulator. A driver is any circuit which, when triggered, drives the modulator with a rectangular pulse of accurately timed width. A modulator is a circuit which supplies power to the r-f oscillator in the form of a timed, high-amplitude, rectangular pulse. The driver is triggered by the timer in order to maintain the repetition rate of the system. The driver, when triggered, shapes a rectangular pulse of proper time duration which in turn operates the modulator. The modulator then furnishes the high-plate voltage to the r-f oscillator for the predetermined pulsing time. Thus the transmitter function may be carried out by the combined performance of a driver, a modulator, and an r-f oscillator. The modulator acts like a power amplifier for the driver and like a switch for the r-f oscillator.

MODULATOR

A radar modulator, by controlling the operation of the transmitter, causes r-f energy to be produced in short, powerful pulses. The modulator controls the shape, duration, and repetition frequency of the pulses. Usually it exercises control by applying pulses of plate-to-cathode voltage to the transmitter tube. Magnetrons must always be plate modulated. Triode transmitter tubes are often plate modulated, but they may be controlled by pulses applied to the grid, or they may be self-pulsed.

Nearly rectangular modulator-voltage pulses are preferred in most radar systems. A flat top is desired because both magnetrons and triode oscillators shift frequency if the supply voltage changes, and both operate at reduced efficiency if the supply voltage falls below its maximum. A steep leading edge is required in fire-control systems to make possible accurate measurement of range. A steep trailing edge is important when short minimum range is desired. The output obtained while the voltage is dropping from its maximum value to zero contributes little to the useful energy in the pulse, but it does obscure weak echoes from very close objects.

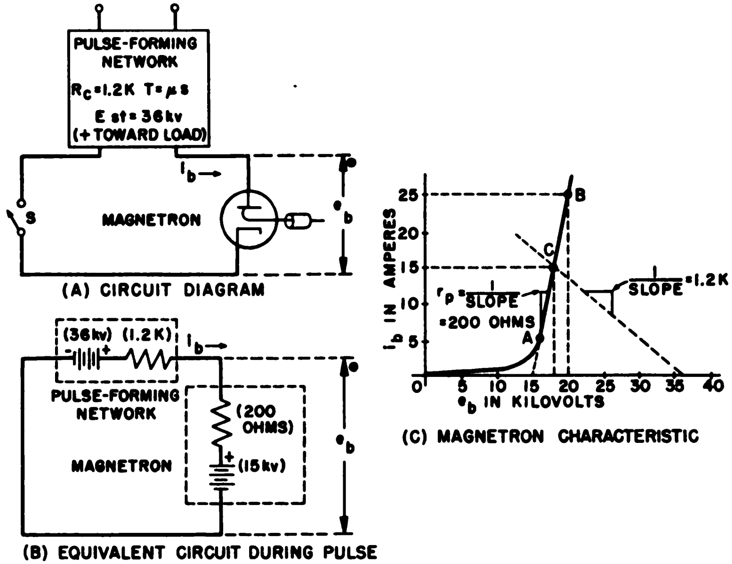
Short pulses (duration of 0.1 to 2.0 μs) required for high resolution are usually produced by means of pulse-forming lines or by blocking oscillators. Long pulses (duration of 2.0 to 20μs) required to provide the pulse energy needed for long-range detection of small objects may be formed in a similar fashion, or they may be produced by multivibrators or by clipping and peaking circuits. In line-pulsing modulators a high-power pulse is formed by a network and delivered directly to the transmitter. In driver-power-amplifier modulators the pulse is formed in a low-power driver stage and is amplified before being applied to the transmitter.

Characteristics of Loads for Pulse-forming Network

A pulse-forming network is connected to a nonlinear vacuum-tube circuit—the plate circuit of a magnetron or triode transmitting tube in line-pulsing modulators and the grid circuit of an amplifier tube in driver-power-amplifier modulators. Neither magnetrons nor triode oscillators draw a plate current proportional to the plate voltage. Amplifier grid circuits are nonlinear because the grid voltage changes from a negative value before the pulse to a positive value during the pulse.

A pulse-forming network is shown in figure 5–1A. It is charged to 36 kv and then discharged through the magnetron. The plate current of a magnetron rises slowly as the plate voltage is increased until a critical value of voltage is reached and then rises very rapidly for any further increase of voltage. Such an i_b, e_b characteristic is shown in figure 5–1C and is markedly nonlinear.

An equivalent circuit during pulse when switch S is first



(A) CIRCUIT DIAGRAM

(B) EQUIVALENT CIRCUIT DURING PULSE

(C) MAGNETRON CHARACTERISTIC

Figure 5–1.—Example of pulse-forming network connected to nonlinear load.

closed is a 36-kv battery in series with a 1.2-K resistor, as shown in figure 5–1B. If the operating point of the magnetron lies somewhere on the straight line *AB* of figure 5–1C, the magnetron is equivalent to a 15-kv battery in series with a 200-ohm resistor representing the plate resistance r_p, and the circuit of figure 5–1B results.

From figure 5–1B, the magnetron current during the pulse is found to be $i_b = \frac{36{,}000 - 15{,}000}{1200 + 200} = 15$ amps. The magnetron voltage is, therefore, given by: $e_b = 15{,}000 + (200 \times 15) = 18{,}000$ volts and the operating point is *C* in figure 5–1C. This point can be located in another way without the use of an equivalent circuit for the magnetron. The pulse-forming network can be considered as a plate-voltage source of 36 kv in series with a 1.2-K load resistor. The intersection of the load line for this source (shown dashed in figure 5–1C) with the magnetron characteristic locates point *C*.

During the pulse, the ratio e_b/i_b is $18{,}000/15 = 1{,}200$ ohms. Thus the network operates as if it were connected to its characteristic resistance and delivers a single 1-μs pulse of voltage equal to one-half of E_{st}. This matched condition results, however, only for the particular value of E_{st} assumed. If E_{st} were reduced, plate current would decrease more than plate voltage and the network would appear to discharge into more than its characteristic resistance. For example, if E_{st} were 29 kv, i_b would be 10 amp, according to figure 5–1C, and e_b would be 17 kv. The ratio $e_b/i_b=1.7$ K is more than R_c; the initial pulse then has an amplitude more than one-half E_{st} and is followed by a series of smaller pulses. If E_{st} were greater than 36 kv, the network would effectively be connected to less than its characteristic resistance and an initial low-amplitude pulse would be followed (if *S* remained closed) by alternately negative and positive pulses. Note that the steep slope of the i_b, e_b curve of the magnetron causes a large change in the amplitude of the current pulse to be associated with even a small change in the amplitude of the voltage pulse.

Modulation Amplifier

A simplified schematic of a modulation amplifier is shown in figure 5–2. The transmitter is keyed or pulsed by the ON-TIME negative output from the modulation generator which is applied to grid 1 of the double triode *V1*. This tube serves as a 2-stage voltage amplifier and is capacitance-coupled by *C2* to *V2*, a power amplifier. The output of *V2* is essentially a square wave with a voltage swing of about 250 volts. The leading edge of each positive swing, however, is modified by a shunt circuit consisting of capacitor *C3*, resistor *R18*, and twin diode *V3*. It is the function of this shunt circuit to prevent the leading edge from rising so sharply as to cause premature oscillation in the magnetron. When the plates of *V2* swing positive, diode *V3* conducts and capacitor *C3* charges rapidly. The rise in grid voltage at pulser tube *V4* is delayed until capacitor *C3* is charged. The trailing or negative edge of the wave is not delayed as diode *V3* will not conduct when the plate of *V2* swings negative.

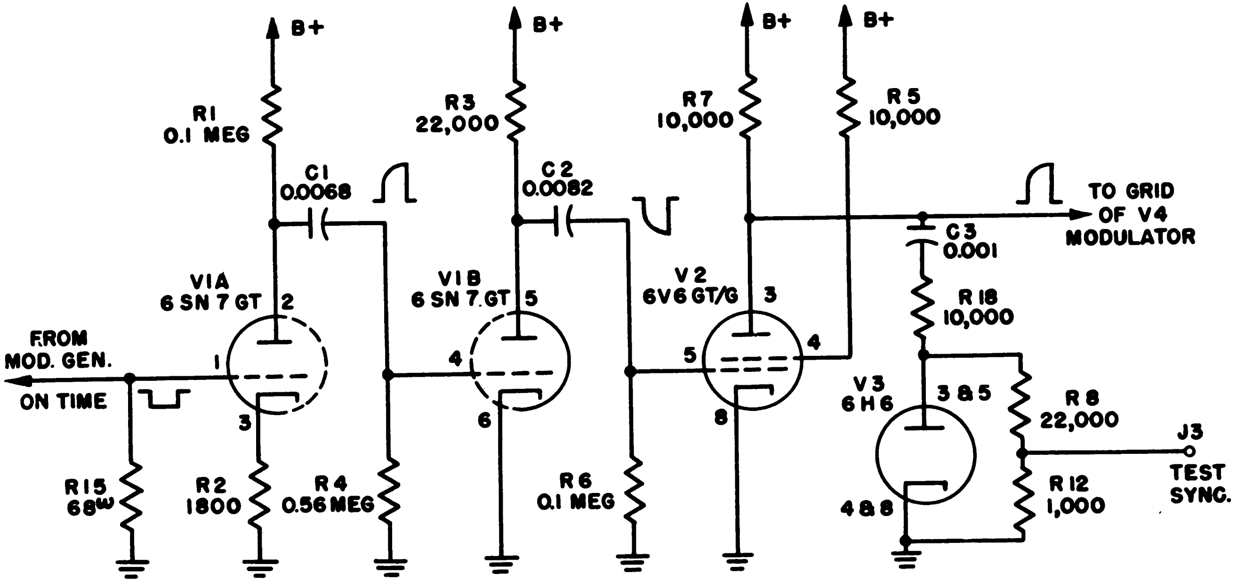


Figure 5–2.—Simplified schematic of a modulation amplifier.

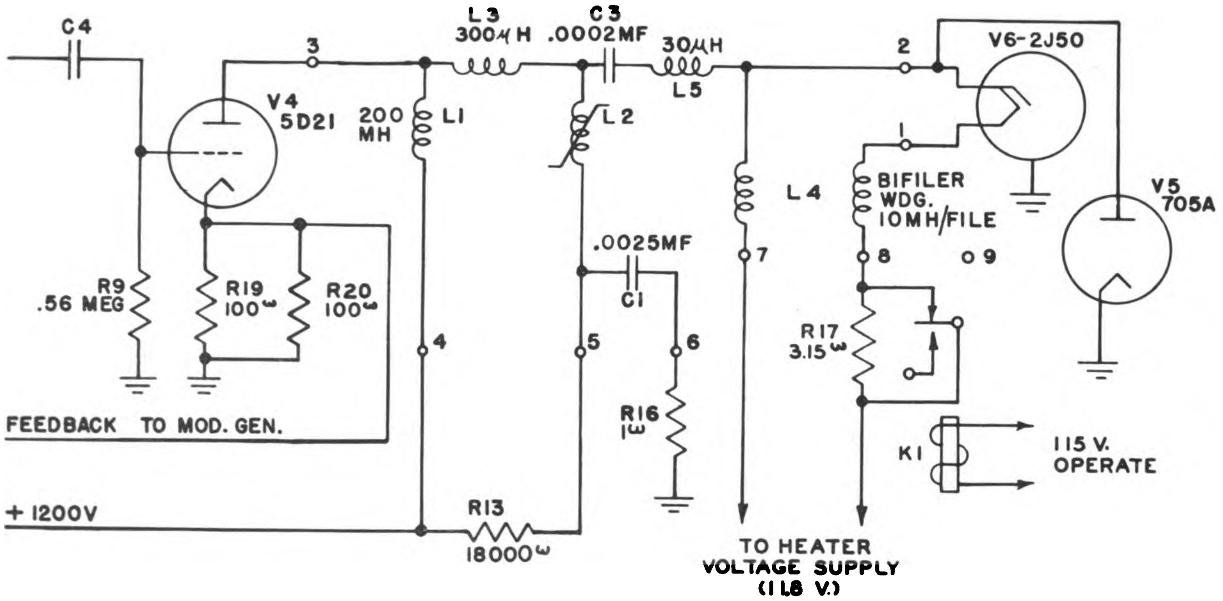


Figure 5—3.—Simplified schematic of a pulser circuit.

A simplified schematic of a pulser circuit is shown in figure 5–3. The output of the modulation amplifier and the pulser-shaping tube (fig. 5–2) is applied to the grid of the pulser tube *V4* through capacitor *C4*. When *V2* is not conducting, its plate potential approaches +300 volts and capacitors *C4* and *C3* become charged. When *V2* conducts, capacitors *C3* and *C4* start to discharge through *V2*. The discharge action of *C4* holds the grid of *V4* at a negative potential so that it does not conduct. When the positive portion of the ON-TIME wave (tube *V2* cutoff) is applied to *C4*, the grid of *V4* rises to a potential which allows *V4* to conduct. See (A) of figure 5–4. During the cutoff period when *V4* is not conducting, no current flows through *L1* and *L2* and capacitors *C3* and *C1* become charged to 1,200 volts. *L1* is a linear inductor of 200-millihenry inductance, while *L2* is a nonlinear coil whose inductance changes suddenly from about 2 henries with very small values of current through the coil to about 150 microhenries when the coil becomes saturated.

It can be seen in figure 5–5 that, if the current is changed in a narrow range around zero, the flux density changes rapidly with current. But beyond a critical value (about 20 milliamperes), saturation occurs and the flux density is substantially constant. As soon as the current exceeds this critical value, either positive or negative, the coil becomes saturated and current changes are no longer accompanied by changes in flux density. This results in a very low inductance during periods of saturation.

During the period that *V4* is conducting (on time), current flows from the +1200-volt source through inductor *L1*, through the plate-to-cathode path in *V4*, and through parallel resistors *R19* and *R20* to ground. The current rises rapidly at first due to *C3* discharging to about 200 volts, then assumes a gradual rise due to the inductive circuit (see (D) of figure 5–4), and finally reaches a value of about 0.54 ampere before being cut off by the positive swing of the pulse from the modulation generator. This cutoff is con-

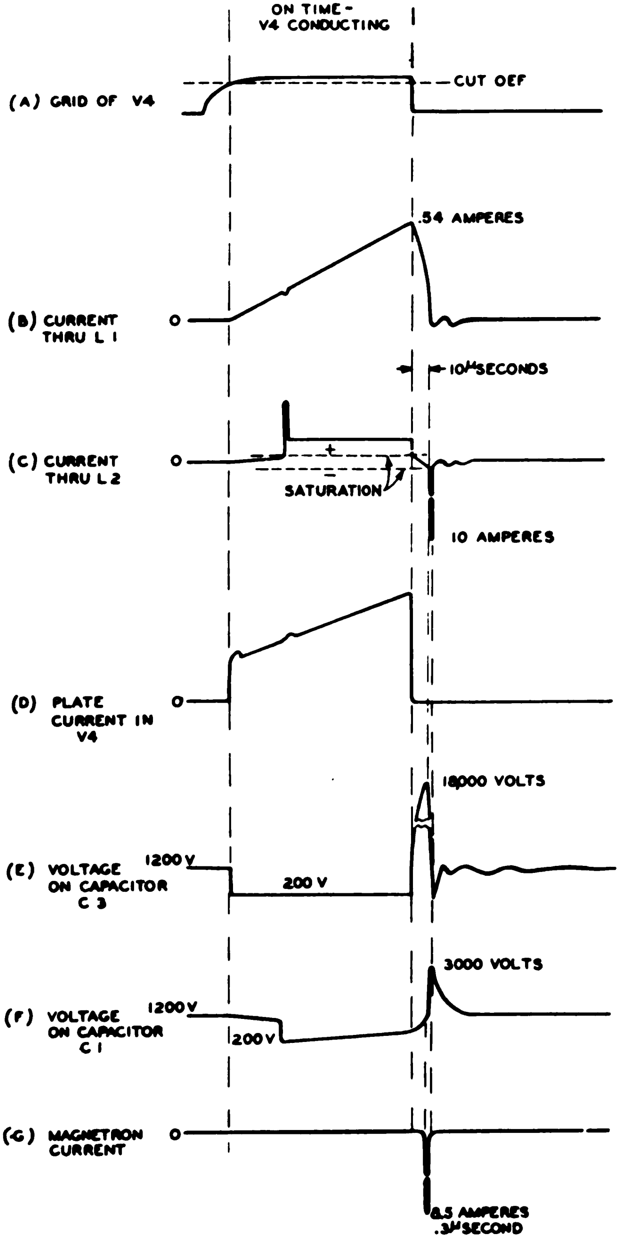


Figure 5–4.—Transmitter wave forms.

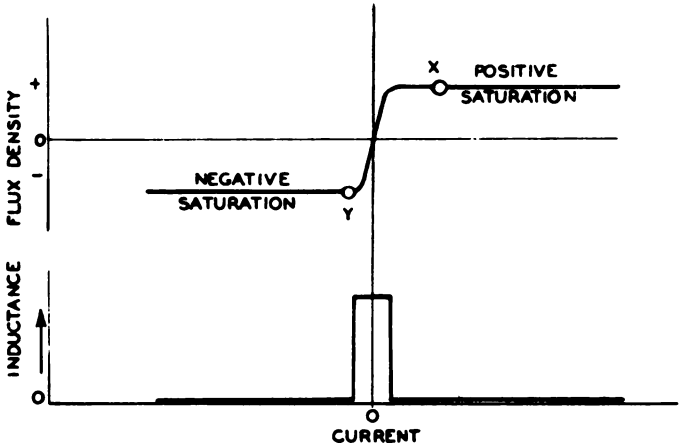


Figure 5–5.—Nonlinear coil characteristics.

trolled by the feedback to the cathode of the on-time multivibrator in the modulation generator as follows: when the current through the cathode resistors reaches about 0.54 ampere, the potential at the junction of these resistors and the cathode of *V4* reaches a peak value of about +27 volts. This is fed to grid 1 of *V2* in the modulation generator and ends the on-time multivibrator cycle.

While tube *V4* is conducting, a biasing current for the nonlinear coil flows through *R13*, inductors *L2* and *L3*, tube *V4*, and the cathode resistors to ground. See (C) of figure 5–4. Capacitor *C1* does not completely discharge until the current through *L2* has reached saturation. At this point the coil reactance becomes almost zero and capacitor *C1* discharges rapidly to about 200 volts. After *C1* has discharged, the current through *L2* is maintained near saturation by the direct current supplied through resistor *R13*.

When the grid of tube *V4* swings negative, the tube is cut off and flow of current through the linear inductor *L1* is abruptly terminated. Due to the high inductance of the linear coil, the sudden collapse of its magnetic field creates a voltage which rises to about 18,000 volts. This potential causes current to flow through capacitor *C3*, inductor *L5* (a

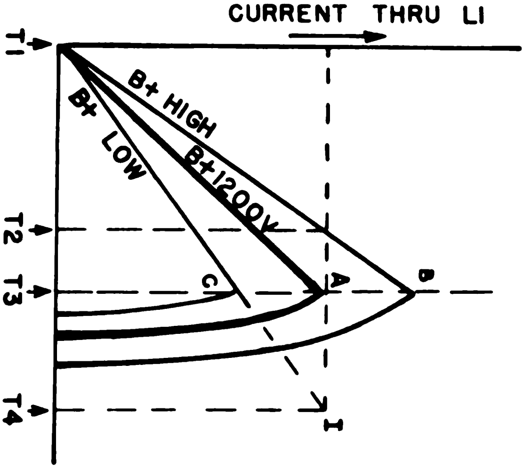


Figure 5–6.—Effect of power supply variation on L1 current.

pulse-shaper coil), and diode *V5* to ground. A current also attempts to build up through the nonlinear inductor *L2*, capacitor *C1*, and resistor *R16* to ground. This is a reversal in direction of current flow through inductor *L2*. The current thus decreases from near positive saturation through zero and increases in the other direction until negative saturation is reached. Because of the large inductance of *L2* during this period, about 10 microseconds are required for the coil to reach negative saturation. During this interval the charge on capacitor *C3* builds up to about 18,000 volts.

When inductor *L2* reaches negative saturation, its reactance suddenly drops and capacitor *C3* discharges through inductor *L2*, capacitor *C1*, and resistor *R16* to ground. This action applies about 12,000 volts across the magnetron. During the period that the voltage is above 10,500, the magnetron impedance drops and it oscillates at its inherent frequency. The length of the current pulse is about 0.3 microseconds and the peak current is about 8.5 amperes. The pulse shape is shown in (G) of figure 5–4. The entire 18,000–volt charge on capacitor *C3* does not reach the magnetron because of voltage drops across *L2*, *C1*, and stray capacitances.

When the voltage applied to the magnetron drops below 10,500, the input impedance of the magnetron suddenly increases and it may produce a train of damped oscillations following the main pulse. These residual oscillations are quenched by the action of the carefully selected bifilar winding coil *L4*. The winding of the bifilar coil *L4*, which is connected to *L5*, presents a low impedance shunt to ground across the magnetron when the voltage applied to the magnetron drops below 10,500. This discharges capacitor C*3* completely and prevents further oscillations of the magnetron.

The heater current is supplied by transformer *T2* through coil *L4* to the magnetron. Coil *L4* is wound in a bilfilar manner so that there is no potential gradient between identical points along the windings. This coil also serves as a high-frequency choke and permits the use of a low-insulation transformer winding for the magnetron heater. The voltage actually applied to the magnetron filament is 6.3 volts except during application of high voltage to the transmitter, and, during this period, it is lowered to about 4.5 volts for the purpose of obtaining increased life. The voltage is decreased by the operation of relay *K1* which removes the short circuit from the series resistor *R17*. This relay is operated by a 115-volt alternating current after the time-delay relay in the control unit has operated.

QUIZ

1. Long pulses required for long-range detection may be produced by a
   a. multivibrator.
   b. clipping circuit.
   c. peaking circuit.
   d. all of the above.

2. The shunt circuit in figure 5–2 which prevents the leading edge from rising sharply and causing premature oscillation in the magnetron is made up of
   a. *C3*, and *R18*.
   b. *C3*, *R7*, and *V2*.
   c. *R7*, *V2*, and *V3*.
   d. *V3*, *R18*, and *C3*.
3. Most r–f oscillators use a/an
   a. fixed bias.
   b. unbypassed cathode resistor.
   c. grid-leak bias.
   d. no bias.

True—False

4. A self-pulsed transmitter system oscillates at a carrier frequency and a pulsing frequency.
5. Amplifier grid circuits are nonlinear because the grid voltage changes from a positive value before the pulse to a negative value during the pulse.
6. The operation of the r-f oscillator in an externally-pulsed system depends on a properly timed, high-amplitude, rectangular pulse.
7. Accurate measurement of range in fire-control systems is made possible by the steep leading edge of the pulse.
8. The transmitter is keyed or pulsed by the on-time negative pulse from the modulation generator.
9. In figure 5–3, the biasing current for the nonlinear coil flows through resistor *R13*, inductors *L2* and *L3*, tube *V4*, and the cathode resistor to ground.
10. The winding of the bifilar coil *L4* presents a high impedance to ground across the magnetron when the applied voltage drops below 10,500.
11. The filament voltage of the magnetron is 6.3 volts during the application of high voltage to the transmitter.
12. The transmitter is an r-f pulse containing oscillations at a frequency for which the magnetron was designed or tuned.
13. Referring to figure 5–3, the discharging action of *C4* holds the grid of *V4* at a negative potential so that it does not conduct.
14. The voltage drop across *L2*, *C1* and stray capacitance, causes the entire 18,000 volt on *C3* to be applied to the magnetron.
15. Magnetrons and triode oscillators draw a plate current proportional to the plate voltage.

CHAPTER 6

RECEIVERS

Receiving system: The purpose of the radar receiving system is to derive information from the radar echoes, separate this information into target coordinate data, display the resulting data at the indicator, and furnish signals to the tracking or computing units. Following is a discussion which tells how radar receivers accomplish this purpose.

The receiver of a radar system must pass and amplify desirable information and, at the same time, minimize unwanted information. Since noise is a determining factor in the limit of detectability, the receiver should have as little inherent noise as possible. Amplification should be available in the receiver for tracking the smallest possible signal, and the dynamic range should accommodate a wide latitude in signal intensities. The bandwidth of the receiver must have sufficient transient response to preserve the details of the signals. The following is a discussion of a microwave fire-control radar receiver.

R-F INPUT AND LOCAL OSCILLATOR

Figure 6–1 shows the r-f section of a radar system together with the receiver circuits. The frequency range covered by this receiver is a 12-percent band centered at 3.3 centimeters. A tuned TR tube at 3.3 centimeters has a bandwidth (between half-power points) of about 30 mc. This is only slightly greater than the bandwidth of a single i-f amplifier stage of the construction used in this receiver. If, therefore, such a tube were used, it would limit the bandwidth of the receiving system. Also, any unbalance of crystals will reflect LO power back to both crystals in like phase so that the noise is not balanced out. Furthermore, with high-efficiency crystal converters a substantial amount of i-f energy goes back through the crystal and part of it converted to image frequency, which is then reflected back by the narrow-band TR tube and reconverted to i-f energy. Since the phase of the voltage and current are usually at variance with those from the normal incoming signal, an apparent mistuning occurs, which varies with the tuning of the TR tube. A broad-band TR tube has been designed that has lower loss than the usual tuned design, and it has been used in this receiver.

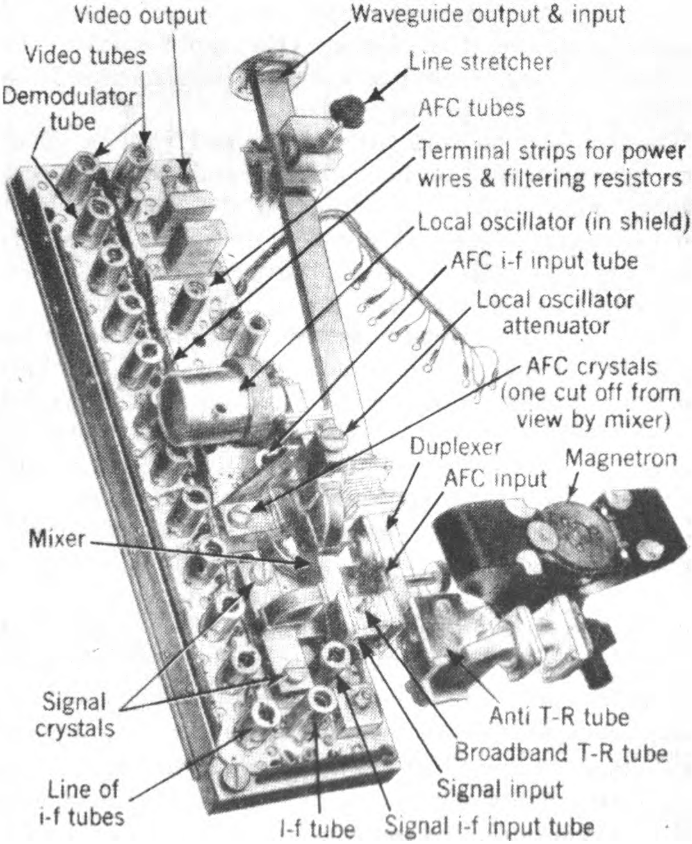


Figure 6–1.—R-f section and receiver circuits.

In order to obtain the lowest possible noise figure, a balanced mixer is used. The unit has been designed so that the signal crystals are well matched into the waveguide. Because of the less critical nature of the problem and because of space limitations, the crystals in the AFC half of the double mixer have not been so carefully matched into the waveguide. The mixer can be seen in figure 6–1.

The AFC circuit is shown in figure 6–2. The input circuit from the balanced mixer consists of the two crystals and two tuned circuits (*C1*, *T1* primary and *C4*, *T2* primary). These two tuned circuits are coupled to the secondaries of *T1* and *T2*, which are connected in parallel and tuned by the input capacitance of the input 6AK5 amplifier tube. This circuit acts very much like a double-tuned circuit loaded principally on the primary side.

The coupling network between *V1* and *V2* is a double-tuned circuit loaded on both primary and secondary. Unlike the other similar transformers in the receiver, no powdered-iron core is used to complete these coils together. The two "ears" resulting on the responsive curve tend to broaden the overall i-f amplifier and discriminator response.

A discriminator circuit has been developed that is particularly suitable for wide-band work, since a high value of the product of gain and bandwidth is obtained with it (about 6 db more than other types tried). The circuit is shown in figure 6–3. In the figure, inductance *L6* and capacitors *C12* and *C14* form a series-tuned circuit tuned to the other side of the intermediate frequency. The frequencies to which these two series-tuned circuits are resonated determine the frequencies of maximum and minimum discriminator output voltage, as shown in figure 6–3B. The proper adjustment of the values of loading resistors *R8* and *R9* straightens the discriminator curve between these maximum and minimum voltages. Inductance *L5* tunes the output circuit capacitance of tube *V2* to the intermediate frequency, 60 mc.

As shown in figure 6–3A, the two halves of the discriminator circuit are balanced to ground. The transient response of the input carrier is at the intermediate frequency of 60

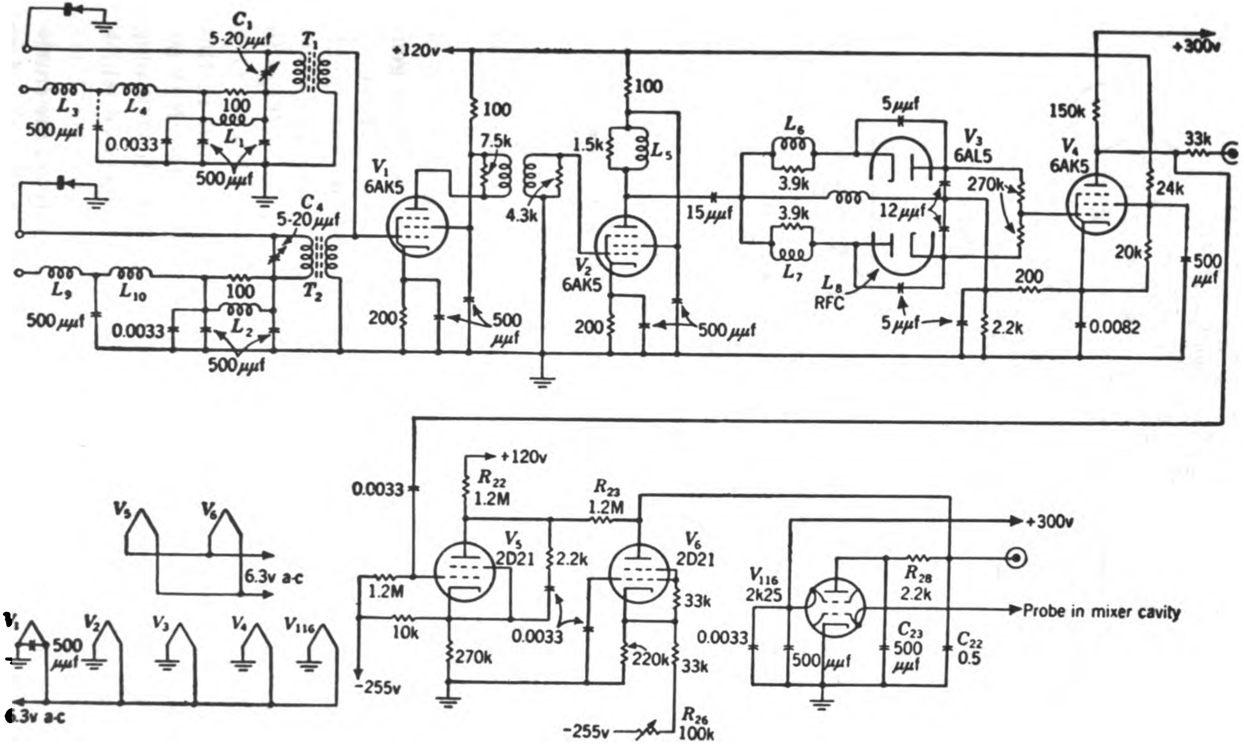


Figure 6–2.—AFC circuit.

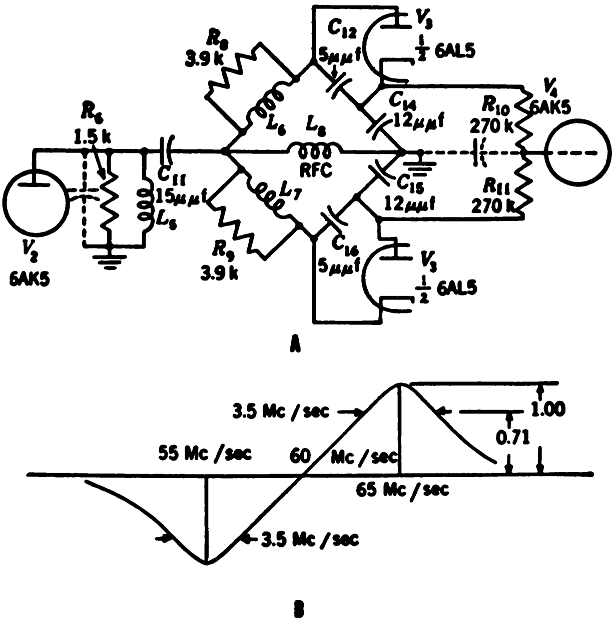


Figure 6–3.—AFC discriminator. (A) Circuit. (B) Output voltage.

mc. This is an advantage over an unbalanced type, since there is no spike left to operate the AFC when the carrier frequency is at 60 mc.

In the remainder of the circuit shown in figure 6–2, tube *V6* is a gas-filled type 2D21 tube used in a saw-tooth generator circuit. The time constant is 1.2 seconds. Tube *V5* is biased so that it does not conduct in the absence of signals on its grid. The 2K25 oscillator tube *V16* is frequency-modulated by the application of this saw-tooth voltage to its reflector through the filter *R28* and *C23* and thus is swept through a frequency range, searching for a signal in this range. The frequency range through which the 2K25 oscillator is swept is adjusted by variation of the 100,000-ohm resistor, *R26*, which adjusts the voltage range over which the 2D21 tube *V6* operates.

It is desirable to have the AFC operate only on the transmitted pulse from the magnetron and that this pulse does not overload the mixer crystal, since the resulting video pulse would contain 60-mc. components that would operate the AFC no matter what the frequency of the 2K25 oscillator. Sufficient attenuation is introduced between the transmitting waveguide and the AFC mixer to allow only enough transmitted power to enter the mixer to produce a peak current of 1 ma. in the crystals. This produces 0.2-volt r.m.s at the intermediate frequency across the crystal when the proper amount of LO power is applied. The AFC circuit should not operate on less than about 0.02-volt r. m. s., since it might then operate on the side lobes of the transmitted pulse and hold the oscillator of normal frequency. Since the 2D21 tube, *V5*, under normal conditions requires about 13 volts on the grid to operate it, a voltage gain of about 1,000 from the crystal to the grid is required. This gain expressed in decibels voltage gain without regard to impedance level is distributed as follows:

	Decibels
Gain from crystal to *V1* grid	6
Gain from *V1* grid to *V2* grid	15
Gain from *V2* grid to *V4* grid	3
Gain from *V4* grid to *V5* grid	36
Total gain	60

The 0.1-μsec input pulse is stretched out to about 5 μsec at the plate of *V4*.

To avoid false directional information resulting from transmitter pulling during the scanning cycle, the AFC circuits should be capable of acting fast enough to follow the transmitter. In figure 6–2, tube *V5* may be considered as a very low impedance source when it is operating. The principal time constant of the filter is the one formed by the resistor *R23* and capacitor *C22*; it must be kept as small as possible. This time constant is 0.6 second, which is as little as can be tolerated if the saw-tooth voltage is not to affect the frequency of the 2K25 oscillator too much. In spite of this time constant, which is long with respect to the error signal period, there is sufficient gain around the AFC feedback loop to eliminate almost completely any 30-cycle frequency modulation of the intermediate frequency. The small amount of frequency modulation remaining does no noticeable harm because of the small curvature in the center of the receiver selectivity curve.

The intermediate frequency of 60 mc. is sufficiently high to prevent almost all difficulty with wrong-sideband operation.

RECEIVER INPUT CIRCUIT

The receiver input circuit at the intermediate frequency consists of three coupled tuned circuits as shown in figure 6–4. Each crystal of the balanced mixer is shunted across a tuned circuit and appropriate filters are provided so that the d-c crystal current may be measured. Each of these tuned circuits is inductively coupled to a secondary coil with the aid of a powdered-iron core. The two secondary coils are connected in parallel across the input of the first amplifier tube. The loading across the tube input circuit is kept at a minimum and the crystals furnish practically all the loading

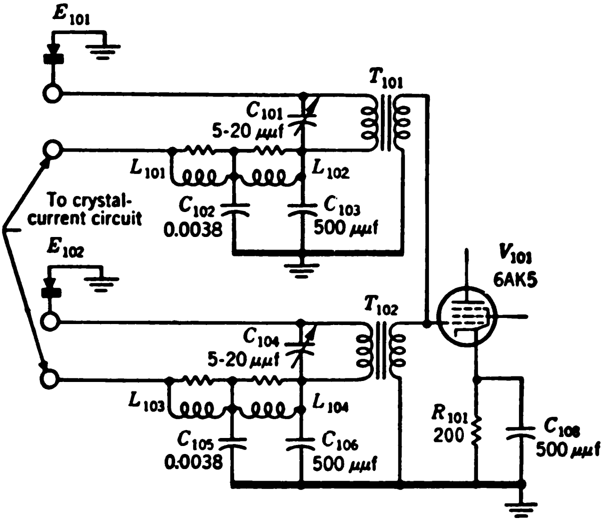


Figure 6–4.—Receiver input circuit at the intermediate frequency.

on their respective tuned circuits. An input circuit of this type is more critical than either the single-tuned circuit or double-tuned circuit with loading on primary and secondary, but it has considerably more gain. The r-f input elements are closely coupled to the i-f input circuit if high-efficiency crystal converters are used. Changes in the r-f elements may change the tuning of the input i-f circuit under these circumstances. The broad-band TR tube and balanced mixer have reduced the possibility of serious changes in the r-f elements; consequently, in practice the i-f input circuit is uniform in response for signal frequencies located anywhere in the 12-percent r-f band. The i-f input circuit also is noncritical in tuning adjustment when tubes are replaced.

Since a large amount of noise in the receiver is generated by the input tube or tubes, high gain in the input transformer produces a high level of signal at the grid of the first tube to override the noise. The loading on the secondary circuit is kept at a minimum to give high gain. The primary circuits are made as low a ratio of inductance to capacitance as is consistent with proper bandwidth, giving higher gain and making the circuit more stable with variation in the tube input impedance and variations in r-f input circuit.

RECEIVER INPUT STAGES

The first two stages of the receiver are of the low-noise type using two triodes. The circuit is shown in figure 6–5. The input triode, or grounded-cathode triode, is a 6AK5 tube with plate and screen connected together. The grid to screen-and-plate capacitance is tuned out by an inductance *L105* from grid to plate. The second triode, or grounded-grid triode, is one-half of 6J6 double triode, which obtains its bias from a 120-ohm resistor *R103*.

INTERMEDIATE-FREQUENCY AMPLIFIER

Double-tuned circuits are used in this receiver as they are definitely less sensitive to variations in component param-

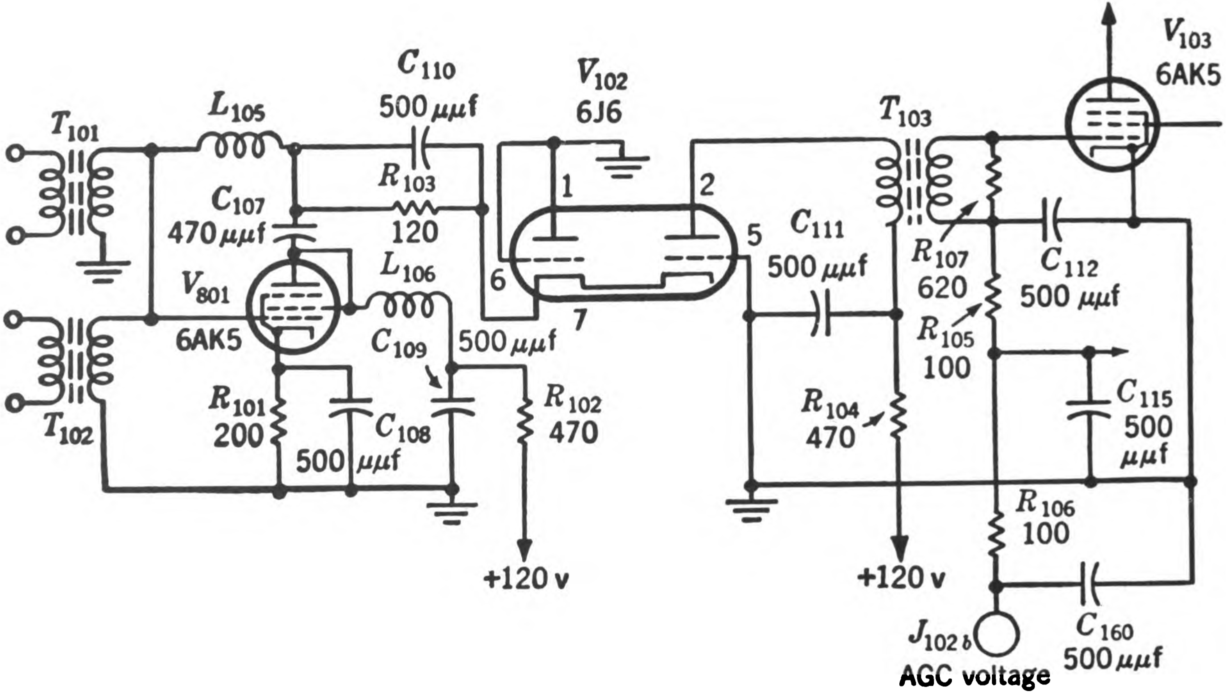


Figure 6–5.—Low-noise i-f stages of a receiver.

eters, and the overall amplifier is more stable than in other circuits, (single-tuned circuits). The double-tuned circuits have some advantages in overall gain-bandwidth. Another advantage is that the input and output circuits of an amplifier stage can be kept more or less independent of each other, because the tuned circuits do not have to be returned to ground but may be returned directly to an independent cathode lead when the 6AK5 tube is used. A further advantage of double-tuned circuits is the elimination of the interstage coupling capacitor—an elimination that decreases the grid-circuit time constant.

The 6AK5 tube was chosen instead of the 6AC7 as an i-f amplifier tube for several reasons. The input-and-output capacitance tolerances of the 6AK5, which are only half as large as those of the 6AC7, allow a more critical circuit and, therefore, more gain per stage. The 6AK5 tube has two cathode leads, which allow a great reduction in the coupling of the input and output circuits of the tube and reduction in chassis currents that might couple amplifier stages to produce regeneration. It is simpler to obtain wide bandwidth, and the components, such as bypass capacitors, are smaller at high frequencies than at low. The 6AK5 operates better at high frequencies, takes less space, and uses less power than the 6AC7.

In a multistage amplifier using double-tuned interstage coupling circuits and having a bandwidth that is as large a fraction of the midfrequency as the present one, it is advantageous to use unequal *Q's* in the primary and secondary circuits. If the *Q's* are equal, it is impossible to obtain sufficient asymmetry to counteract the slope of the top of the response curve caused by the variation with frequency feedback through the plate-to-grid capacitance of the tube.

Figure 6–6 shows a schematic circuit of two typical amplifier stages of this receiver. One provides for applying gain-control voltage to the grid and the other does not.

The coupling between primary and secondary is obtained by means of an iron core with some capacitance coupling obtained by having the grid and plate ends of the secondary

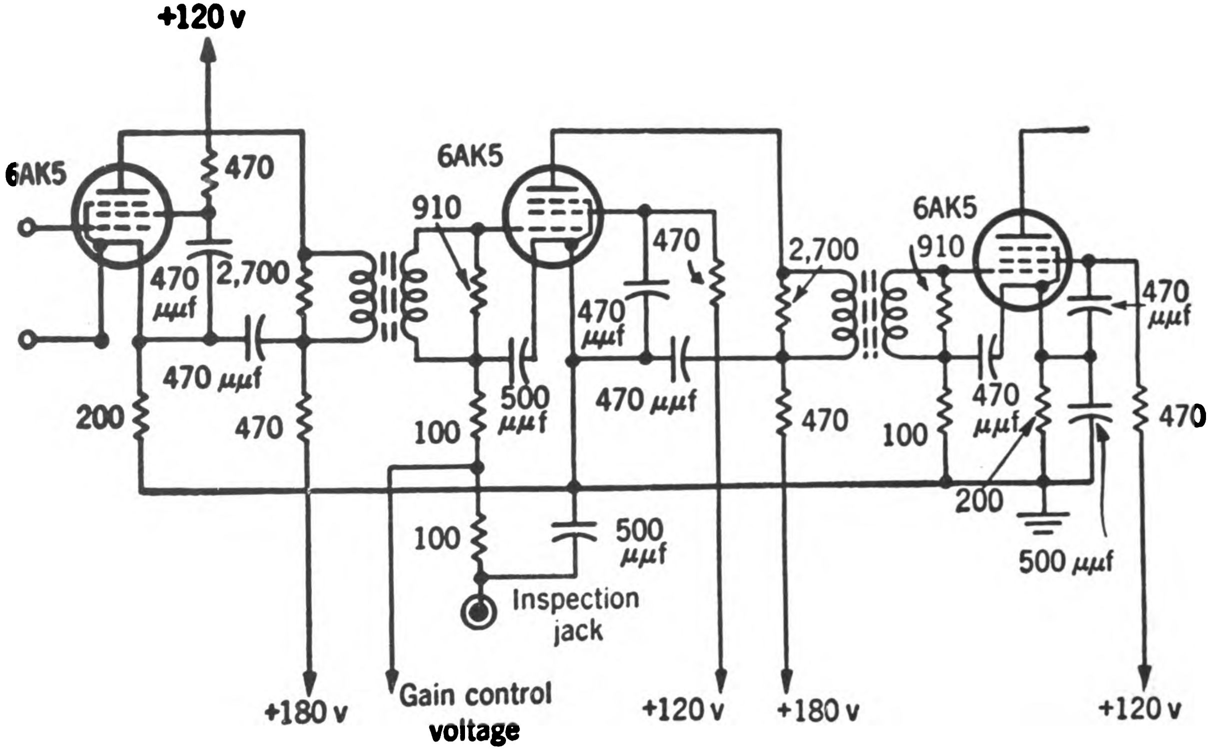


Figure 6—6.—Circuit of two typical amplifier stages.

and primary near each other. The iron core reduces the coil size and the inductive field associated with it.

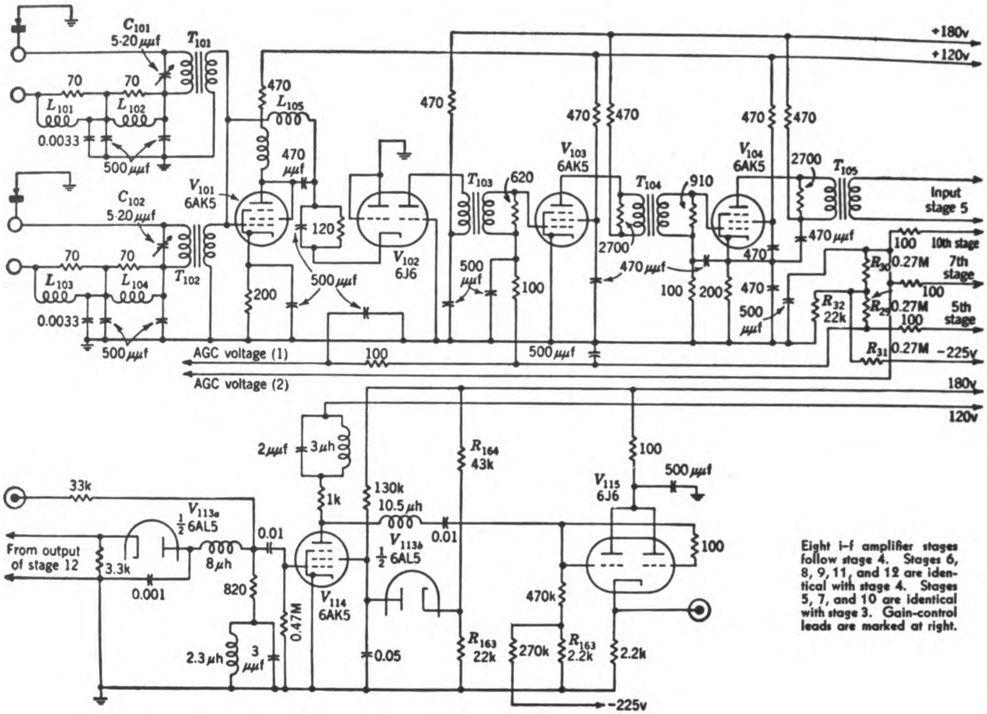
Intermediate-frequency coupling networks that are different from the typical one are the input transformer network, the transformer network between the second and third i-f tubes, and the transformer network between the last i-f stage and the second detector. Since the transformer network between the second and third i-f tubes has loading only on the secondary, the transformer coupling coefficient has been changed so as to raise the gain of this stage and thus reduce the effect of noise from the third i-f tube.

The last i-f transformer is the same as the typical i-f transformer just described. The only change in the network is the use of a 3,300-ohm loading resistor across the secondary of the transformer. This change compensates for the loading of the diode.

The circuit diagram of the signal channel of the radar receiver is shown in figure 6–7. In addition to the features already mentioned, you will note that tubes *V103*, *V105*, *V107*, and *V110*—which have gain-control connections to their grids—have no cathode resistors. The reason for this is that better gain control is obtained when the bias is small if the cathode resistor is omitted. The initial voltage furnished to these grids by the gain control is −2 volts. When the gain control is disconnected and the receiver power is on, a bias is furnished by the −255 volt supply and by the voltage divider resistor *R31* and *R32* through resistors *R29* and *R30*. Since the impedance of this network is high, it has no effect when the low-impedance gain control is connected. Tubes *V103* and *V105* are furnished gain-control voltage from one source with a long time constant, and tubes *V107* and *V110* are furnished gain-control voltage from another source with a short time constant.

SECOND DETECTOR AND VIDEO AMPLIFIER

The second detector and video amplifier, as shown in figure 6–7, consist of tubes *V113*, *V114*, and *V115* and their associated circuits.



Eight i-f amplifier stages follow stage 4. Stages 6, 8, 9, 11, and 12 are identical with stage 4. Stages 5, 7, and 10 are identical with stage 3. Gain-control leads are marked at right.

Figure 6–7.—Circuit of the receiver.

The input capacitance of diode *V113a*, consisting of one-half of a 6AL5 tube, is 7.4 μμf. This is the same as the input capacitance of a 6AK5 tube in the i-f amplifier. The loading of this diode and circuit on the i-f transformer is about 1,060 ohms. The diode-load resistance is 820 ohms. The gain from the i-f amplifier tube grid driving the diode to the diode-load resistor is 5 db (voltage gain), where the input is measured in r-m-s volts (at 60 mc.) during the pulse, and the output is measured in peak-pulse volts.

The normal size of signals while the receiver is operating with automatic gain control is 0.6 peak-pulse volt at the output of *V113a* (negative), and 2.25 peak-pulse volts at the plate of *V115* (positive).

The output pulse from the second detector is negative to allow limiting action by the first video-amplifier tube *V114*. No bias is applied to *V114*. Any positive voltage on the grid causes grid current to flow through the 0.47-megohm grid resistor and bias the tube, thus giving d-c restorer action. The time constant of the grid circuit is long enough that the 30-cycle modulation, caused by the antenna feed nutation when the target is not on the antenna axis, is little affected in phase.

The screen voltage of tube *V114* is 50 to 55 volts and is obtained through a resistor from the regulated +180 volt supply, since no low-impedance source of 50 volts is available. The 130,000-ohm screen resistor stabilizes the tube when the large grid resistor is used and equalizes the gain of different tubes. However, when signals occur a large part of the time, or when there is a great deal of noise, the average grid voltage becomes considerably negative, and less average current is drawn by the screen. The voltage drop in the 130,000-ohm screen resistor becomes less and the screen voltage higher. This causes more current to flow in the plate circuit when the grid is instanteously at zero potential. Under these conditions an input signal that takes the grid from zero voltage to plate-current cutoff causes a greater output voltage. This is not desirable since the increased signal may overload later amplifier tubes as well as change intensity of light output of intensity-modulated cathode-ray tubes when the duty ratio changes.

To reduce the higher output voltage, a lower-impedance (14,400-ohm) voltage divider composed of *R163* and *R164* and giving 60 volts is connected by means of diode *V113b* to the screen of the amplifier tube *V114*. If the screen voltage rises above 60 volts, current flows through the diode and thereby makes the screen-voltage supply circuit have an impedance about one-tenth its former value. This aids greatly in stabilizing the screen voltage and keeps the maximum output voltage much more constant.

The output cathode-follower 6J6 tube *V115* has both halves connected in parallel. The cathode circuit is designed to feed into a 75-ohm line with a d-c path through a 75-ohm resistor connected at the far end of the line. The normal output is 0.75 volt, and the limited output (limited by *V114*) is 1.5 volts.

AUTOMATIC GAIN CONTROL

In the presence of large amounts of noise a desired signal can be more readily distinguished if peak-voltage values are used. This receiver has a circuit in which the peak-pulse voltage is measured each time the desired target signal occurs. This voltage is retained in the circuit until just after the next desired pulse voltage. The circuit therefore introduces a delay approximately equal to the repetition period and has no attenuation for any frequencies that may be present in the form of amplitude modulation of the pulses. It is essentilly an all-pass circuit, which has delay but no attenuation. If no further attenuation is added, such an inverse feedback loop oscillates at f/2, 3f/2, 5f/2. . . . and has maximum degeneration at 0, f, 2f, 3f, . . . where f is the repetition frequency of the system. It is necessary to provide sufficient attenuation at f/2 and higher frequencies to prevent oscillation. Any low-pass filter that furnishes the proper attenuation at f/2 causes still further delay and slows up the AGC action.

The low-pass filter of the AGC circuit must not have too low a cutoff frequency or the delay will be apparent at the direction-error modulation frequency. This delay would not be serious except for some applications, if it were constant; but it is not constant. A maximum of 10° total variation in phase shift in the whole radar system at the direction-error modulation frequency, or about 1 millisecond delay variation at that frequency, is allowable.

The low-pass filter could have a cutoff frequency below the direction-error modulation frequency so that the AGC would have no effect at the modulation frequency. The modulation then could be obtained from the video signals. There is the disadvantage, however, of too little margin between the fading frequency of 5 c. p. s. and conical-scan frequency of 30 c. p. s. to allow sufficiently small variation in phase shift at the modulation frequency of 30 c. p. s. in the face of tube variations.

Another disadvantage of a very low cutoff frequency in the AGC filter is that a strong sudden interfering signal gives a high AGC bias that is delayed so long in reaching the amplifier grids that the filter storage elements are well filled. The bias then takes the amplifier tubes well beyond plate-current cutoff. Since no signal can then pass through the amplifier, the feedback loop is broken and the feedback system can no longer aid itself in keeping a constant output and therefore cannot aid in restoring the receiver to a condition where it can handle normal signals again. The filter then takes its own time in discharging the capacitors. This takes so long (1½ to 3 seconds) that the radar system may well have lost its target.

Slow time constants in AGC systems are likely to be so close to the time constant of the radar system that poor target tracking or even oscillation of the radar system as a whole may occur.

To obtain good range-error signals you should have constant-amplitude output signals so as to eliminate apparent range shift due to nonlinear distortion of the varying amplitude signals that do not have instantaneous rise in amplitude (vertical sides).

In this receiver each pulse is measured and the measured

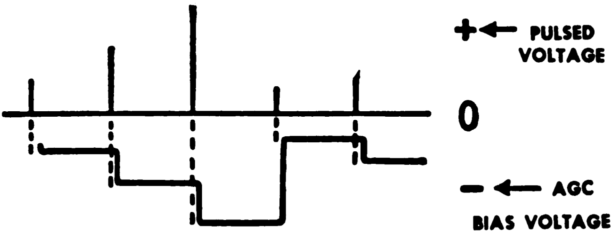


Figure 6–8.—Relation of AGC voltage and pulse signals.

voltage is held over until the next pulse from the same target is received. It is then applied as bias to the i-f tubes, which are controlled by the AGC feedback circuit until the next pulse arrives. As soon as this next pulse is measured and the previous pulse has disappeared, the newly measured voltage is used as AGC bias, as shown in figure 6–8. When the incoming signals are modulated at a frequency equal to one-half the repetition rate (f), and the feedback loop is broken where E_c^2 is applied to the i-f tubes, the result is shown in figure 6–9. You can see that, when the incoming signal is large, a small bias is applied to the receiver and when the incoming signal is small, a large bias is applied to the receiver. In other words, the feedback voltage is in phase with the incoming signals so that the output increases indefinitely to the point of oscillation if the loop gain is sufficient. Voltage at one-half the repetition frequency must be attenuated sufficiently to prevent this oscillation. In this receiver a low-pass filter is used to allow not only degeneration at low

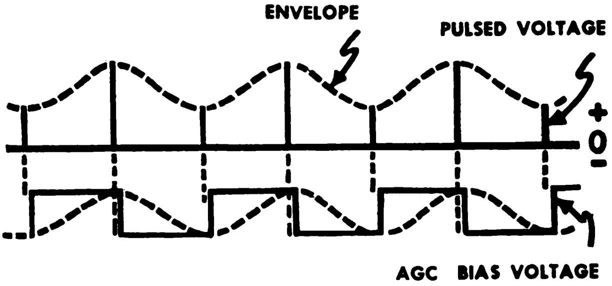


Figure 6–9.—Pulse signals amplitude modulated at half the repetition rate.

frequencies but also sufficient attenuation at high frequencies to prevent trouble at half the repetition frequency.

The effect of a single-time-constant low-pass RC filter is shown in figure 6–10. A step function applied to the input of the circuit shown in figure 6–10A produces the output in figure 6–10B. The response to the voltage of figure 6–9 is shown in figure 6–10C. The phase of the feedback is unchanged—that is, the minimum bias occurs at the same time of maximum signal; the feedback voltage is in phase with the incoming signal; and the circuit is regenerative at this frequency. The amplitude of the feedback voltage is reduced, however, and oscillation may be prevented. You can see that no matter how long the time constant, the phase is unchanged and the only effect at this frequency is a reduction of amplitude. In other words, the delay caused by the pulsed data and the delay caused by the filter do not add directly.

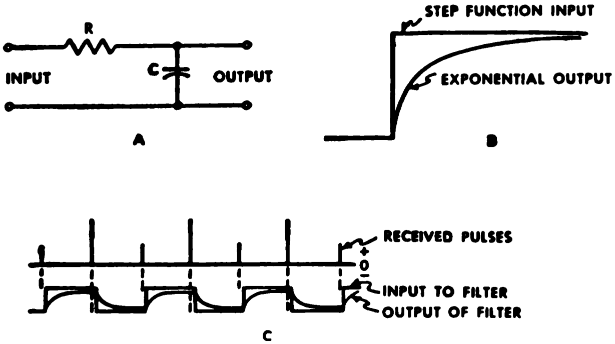


Figure 6–10.—Effect of single-time-constant low-pass RC filter.

To obtain an output signal of convenient size and still have high gain around the feedback loop, you must provide a delay bias. An advantage is gained by putting this bias after the filter instead of before it. The filter action removes some frequency components, with the result that the amount of variation in voltage after the filter is small. When the AGC delay bias is applied after the filter, the bias merely subtracts a d-c voltage from the voltage applied to the i-f amplifier grids. At the input to the filter, however, frequencies are not yet removed and may be relatively large. If the bias is applied here, the peaks of these higher-frequency voltages may go below the bias level and be cut off. During the intervals in which this voltage is cut off, no useful information is being applied to the filter. The loss of this information is a form of distortion that may seriously affect the direction-error signal and hence the automatic-tracking capability of the radar.

The purpose of the AGC is to prevent distortion, but it may actually cause considerable distortion if the feedback voltage is not properly applied to the i-f amplifier. If the feedback is applied to only one i-f tube, strong signals produce so much bias that the tube is cut off a large part of the time. This action causes much information to be lost and greatly increases the apparent modulation percentage. It is also inappropriate to apply the AGC bias to the first one or two amplifier stages, since this impairs the signal-to-noise ratio when signals are weak and noise is operating the AGC. On the other hand, control must be applied at a sufficiently early point in the amplifier to preclude the possibility of overload or limiting ahead of the control point. In the receiver under discussion the AGC voltage is applied to the tubes of four amplifier stages—the third, fifth, seventh, and tenth. This allows the signal to attain a reasonable level above noise, and then holds the signal within a region around this level until the final amplification to the desired level for demodulation.

A good arrangement consists of two filters, one that passes frequencies from zero to well above the error-signal frequency and one that passes frequencies from zero to a cutoff well below the error-signal frequency. The AGC voltage for the seventh and tenth i-f tubes traverses only the filter with the high-frequency cutoff, and the AGC voltage for the third and fifth i-f tubes passes through both filters. The gain around the feedback loop at low frequencies is at least twice as great as at high frequencies, and the output is more constant at low frequencies, but the error-signal output has been doubled by this means.

DEMODULATOR CIRCUIT

The purpose of the demodulator circuit of the receiver is to take in all received signals, select the pulses belonging to one signal, and from these selected pulses obtain voltage outputs to operate the direction servos and range servos as well as the voltage to control the gain of the receiver automatically. It also has provision for manually controlling the gain of the receiver.

This circuit is shown in detail in figure 6–11. The input signal with the AGC operating is 0.75 volt positive for the signal that is controlling gain and about 1.5 volts maximum for any others and comes from a 75-ohm transmission line.

The first two tubes of the circuit in figure 6–11 are wideband video-amplifier tubes. The third stage of amplification also selects the signal from the desired target. This stage consists of two tubes with control grids operated in parallel and the plates operating two separate but similar circuits. These two amplifier tubes normally are nonconducting except at the time the desired signal arrives at the grids. When the tubes are nonconducting, the screen grids are held at a low-positive voltage and the suppressor grids are held at a negative voltage. This assures that the tubes will not conduct during the off period even if the signals are very strong at the control grids. Just before the desired signal occurs, a comparatively slow positive pulse of voltage, or gate, is applied to the screen grids by means of a 7F8 tube used as a cathode follower. The duration of this gate is slightly longer than the period of the signal. While this gate is on, a second gate supplied by a pulse transformer in a blocking-oscillator circuit is applied to the suppressor grids. This second gate has very steep sides and lasts for about half the period of the signal pulse. The relation of these various gates to the input and output signals is shown in figure 6–12. The signal pulse does not have as steep sides as it had on entering the receiver and lasts for about twice as long. Since the signal pulse at the input to the receiver is 0.1 μsecond long, the pulse at the control grids of the gated tubes is about 0.2 μseconds long from the start of the

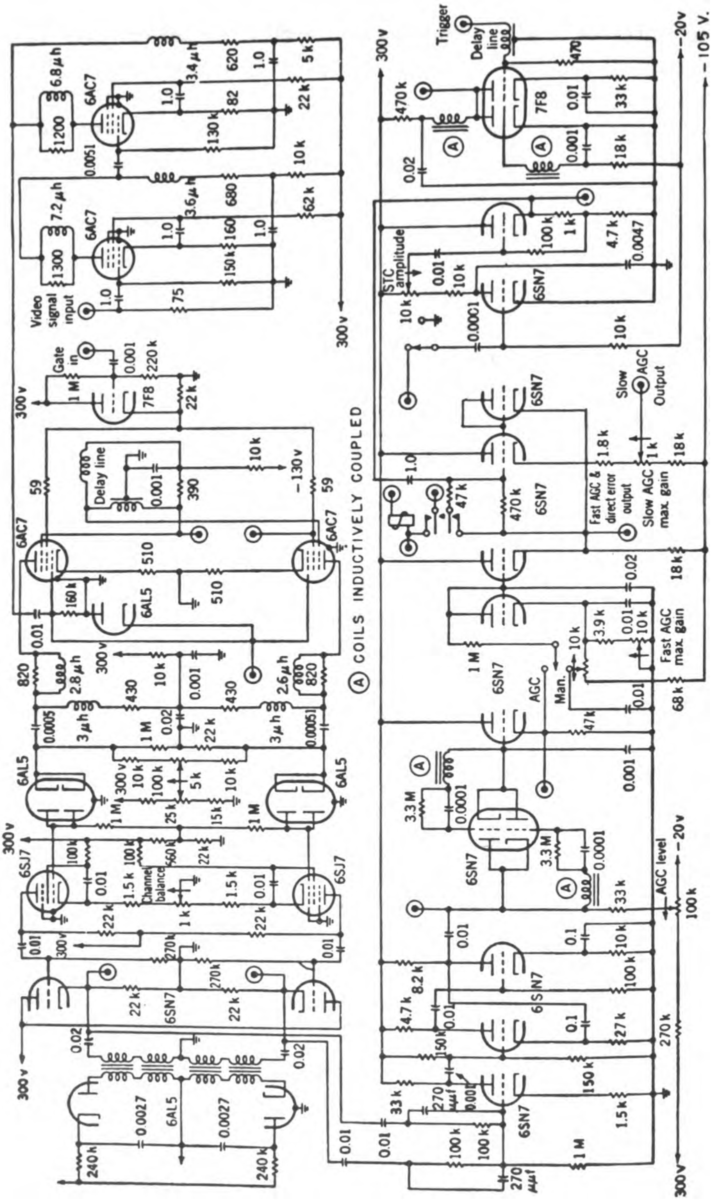


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Figure 6–11.—Demodulator circuit.

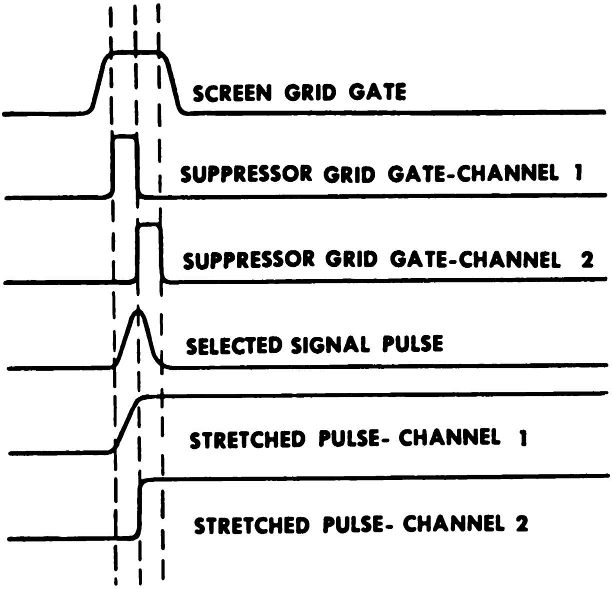

SCREEN GRID GATE
SUPPRESSOR GRID GATE-CHANNEL 1
SUPPRESSOR GRID GATE-CHANNEL 2
SELECTED SIGNAL PULSE
STRETCHED PULSE- CHANNEL 1
STRETCHED PULSE- CHANNEL 2

Figure 6–12.—Gate voltages for signal selection and splitting.

rise to the end of the fall of the pulse. The gate applied to the suppressor grids is about 0.1 μsecond long. The gate is applied directly to one of the suppressors but is passed through a delay line of approximately 0.1 μsecond to the other suppressor; therefore, the end of the gate to the first suppressor occurs at the time of the start of the gate to the other suppressor. This point at which the end of one gate and the beginning of the other occurs is centered on the peak of the signal pulse applied to the control grids. Thus, the first half of the signal pulse is amplified by one tube, and the last half is amplified by the other. If the point of symmentry of the two gates should be shifted from the center of the signal pulse as, for example, a result of change in range of the target, the height and length of pulse output of one tube will be greater than those of the other. This difference in output is later used to operate the range servos for automatic range-tracking; in addition, the two outputs are combined to furnish the AGC voltage.

The signal input to the grids of the gated tubes is composed of all received signals and noise. The average voltage input to these tubes, therefore, varies when any of the signals vary or when the amount of noise relative to the signals varies. The height of the signal from the desired target, with respect to the average input voltage, varies not only when this signal itself varies but when any other signal or the relative amount of noise varies. To provide a base line to which the desired signal can be referred and which is not appreciably affected by the other signals or noise, a d-c restorer diode circuit is included in the grid circuit of the gated tubes. This circuit makes the output of the gated tubes practically independent of all variations except those of the selected signal. For this purpose the time constant of the d-c restorer is moderately long, being about 1,600 μseconds.

The output of the two gated tubes goes to two identical pulse-stretching circuits. These circuits have capacitors that charge very rapidly and discharge slowly. The charging is done through diodes which cease to conduct as soon as the current through them attempts to reverse direction. The charging time of the circuit depends on the plate capacitance of the gated tube, the capacitance of the diode to ground, the grid capacitance of the following tube, the stray capacitance, the plate-load resistance, and the compensation, or peaking, used. The circuit must charge fast enough to have a charging bandwidth as wide as the other video circuits in order to operate in the presence of certain types of interference. This bandwidth is achieved in the same way as in the other video stages.

The discharging time constant of the pulse-stretching circuit is determined by the output capacitance of the diode, the input capacitance of the following tube, the stray capacitance, and the diode-load resistance. The diode-load resistance must be smaller than the maximum allowable grid resistor of the following tube. In any event, values higher than 1 megohm are likely to be too vulnerable to humidity. The discharging time constant used in this unit is approximately 20 μsec.

The purpose of this pulse-stretching operation is to obtain a voltage proportional to and, as nearly as possible, equal to the peak voltage, the stretched voltage to last long enough to allow the charging of a very long time-constant circuit with tubes of reasonable size. The time constant of this very long time-constant circuit must retain its charge essentially constant from one pulse to the next. The pulse-stretching and very long time-constant circuits, combined with their associated circuits, may be regarded as a peak voltmeter preceded by a two-stage pulse stretcher. For an input signal as fast as a 0.1 μsecond pulse of a 25-mc. wave, the output signal is a stepped, or "staircase," voltage. The height of each step from a base line is proportional to the corresponding input pulse height or voltage. This circuit should not be confused with the so-called "boxcar" circuit, which has a voltage output momentarily going down to the base line just before each pulse. Extra filtering is required to remove the high frequencies caused by the boxcar circuit, and thus the overall response of the AGC circuit is slowed down.

The output of the gated tubes has a large component of the gate voltage. If this voltage were allowed to pass through the amplifier, it would severely tax the dynamic range of the amplifier tubes and require larger tubes. To eliminate this voltage from the rest of the amplifier, the diodes of the pulse-stretching circuit are biased to a value that allows only enough to pass through to ensure that the whole signal-pulse height is utilized.

The stretched pulses from the diode circuits are impressed on the grids of a pair of 6SJ7–GT amplifier tubes, one in each of the two channels. The plate resistors are fairly high, since it is no longer necessary to preserve the large bandwidth of the video amplifier. It is necessary only that the stretched pulse reach its peak by the time that the gate for the staircase-voltage generator circuit is applied, which is about a microsecond later than the gate for signal selection. Advantage is taken of this time to obtain extra gain. The cathode circuit to balance the gain of the two channels, and a variable bias on the diodes in the pulse stretcher, permit equalization of the gate-pulse heights.

The output of these amplifiers is applied to the grids of two cathode followers, which drive two circuits—the range discriminator and the remainder of the AGC circuit.

The range-discriminator circuit is fed through the two pulse transformers. The selected signal is split into two parts by the gates of the selector. When the gates are set at the proper range, the two parts of the signal are of equal voltage. But when the gates are off in range, the two parts of the signal have unequal voltages. These two voltages are compared, and the difference is used to operate the range servos. The output signals of the cathode followers feeding the range discriminator are both positive. The sign of one of these voltages is preserved by the pulse transformer and applied to the plate of the diode; the sign of the other is reversed by its transformer and applied to the cathode of its diode. The terminals of the transformer secondaries that are not connected to the diode are connected together and to one side of each of the diode-output filter capacitors. This connection is used as the low-potential side of the output circuit. The load resistors of the diodes are not connected to this low-potential terminal but are connected in series between the high-potential terminals of the diode outputs, and the junction of the two resistors is used as the high-potential output terminal of the circuit. If the pulse voltages applied to the diodes are equal, the diode output voltages are equal, and the junction of the two-load resistors is halfway between these two equal and opposite voltages, or at the same potential as the low-potential terminal of the circuit. If the pulse voltages applied to the two diodes are unequal, the junction of the two-load resistors has a potential with respect to the low-potential terminal of half the difference in the diode output voltages and of the sign of the higher diode output voltage. This is the range-error voltage and is used to operate the range servo circuits. Its sign and magnitude give the direction and amount, respectively, by which the selector gates are removed from the proper range of the signal. The action of this circuit is similar to the discriminator circuit shown in figure 6–3.

The cathode-follower tubes that drive the range-discriminator-diode pulse transformers also feed a network in parallel with these pulse transformers to supply input to the AGC circuits. This network consists of resistors and capacitors which present a reasonably high impedance to the cathode-follower tubes and apply to the grid of an amplifier tube a pulse of voltage equal to the average pulse voltage of the two channels and of the same shape. The output of this amplifier is applied as a negative pulse to the grid of one of the tubes of a circuit that forms a power amplifier with a very low output impedance. This circuit may be regarded as a two-tube analogue of a cathode follower in which low output impedance is secured for both positive-going and negative-going signals.

The low-impedance power amplifier is connected to a 0.001 μf. capacitor through two tubes, which form a switch that is turned on for only a very short time. A blocking oscillator is triggered immediately after the signal-pulse selector gates are turned off. The blocking oscillator turns on these switch tubes slightly after the stretch pulse reaches its peak at the grid of the low-impedance power amplifier. The switch tubes are kept on just long enough for the 0.001 μf. capacitor to reach 90 to 95 percent of the possible final value, which is about 3 μseconds. The blocking oscillator then turns off the switch tubes until the next signal pulse is received one repetition period later. Thus, the voltage across this 0.001 μf. capacitor is the staircase voltage previously mentioned. The action is illustrated in figure 6–13.

The switch tubes are connected in reverse directions so that the 0.001 μf. capacitor may either charge or discharge readily. The blocking oscillator furnishes sufficient voltage to drive the switch-tube grids highly positive no matter what the potentials of the cathodes may be. The impedance of the grid circuits, however, is made high by means of the 3.3 megohm grid-leak resistors and 100 $\mu\mu$f. storage capacitors so that the blocking oscillator can only drive the grids to give a slight grid current. This prevents the blocking oscillator from determining the voltage of the 0.001 μf. capacitor. The

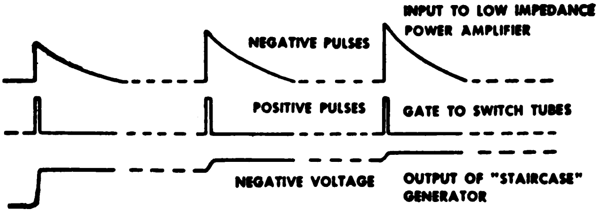

INPUT TO LOW IMPEDANCE POWER AMPLIFIER
NEGATIVE PULSES
POSITIVE PULSES
GATE TO SWITCH TUBES
NEGATIVE VOLTAGE
OUTPUT OF "STAIRCASE" GENERATOR

Figure 6–13.—Action of pulse-stretching circuit.

bias for the switch tubes is furnished by the grid leaks. The time constant of these grids circuits must be long enough to retain sufficient bias to keep the switch tubes cut off when not turned on by the blocking oscillator. This switching circuit is often called a CLAMPING CIRCUIT.

The d-c level is set at this point by a voltage obtained from an AGC level control potentiometer on the input side of switch tubes. The resistance of this voltage source must be low enough that the variable currents through the circuit do not appreciably affect the voltage. Variation of this voltage base line might be serious if its magnitude and the associated time constant should cause a phase shift in the direction-error signal voltage.

The staircase voltage previously mentioned is produced across the 0.001 μf. capacitor, since the time constant between charging times is essentially infinite. This voltage is applied to the grid of a cathode-follower tube. When the AGC-manual switch is in the AGC position, the output circuit of the cathode follower just mentioned is the fast-time-constant filter for the AGC. This filter consists of a 1-meg-ohm resistor and a 0.02-μf. capacitor. The output of the filter is applied to the grid of yet another cathode-follower tube. This cathode follower furnishes voltage to three circuits. It is the low-impedance source of AGC voltage for the i-f amplifier tubes operated through the feedback loop using the fast-time-constant AGC filter only. It furnishes a-c voltage through a capacitor to a tube and filter circuit, which filters out the direction-error voltage and passes it on to the direction servos. It also furnishes voltage to the input of the long-time-constant filter for the AGC system.

A diode circuit is associated with the short-time-constant for the purpose of furnishing the AGC delay bias and for preventing the grids of the i-f tubes from going more positive than −2 volts. The fast AGC max. gain resistor is normally adjusted by disconnecting the receiver video output from the input to this chassis and by varying this resistor until the voltage at the fast AGC output terminal is −2 volts with respect to the chassis. A properly synchronized 0.1 μsec. pulse of 0.75 volt magnitude is then applied to the input of the chassis where the output of the receiver normally connects, and the range gate is properly centered on it. The AGC level control at the input to the switch tubes is then adjusted to give maximum negative voltage at the fast AGC output terminal. The control is turned to reduce the fast AGC output voltage until it just reaches −2 volts. The receiver may now be connected to the chassis input. The circuits are now so adjusted that the AGC feedback loop starts to operate when the selected signal-pulse voltage reaches 0.75 volt at the output of the receiver. The circuit operates as if this delay bias were not present unless the voltage at the plate of the diode at the output of the fast AGC filter becomes more positive than that of the cathode. This results in low distortion.

The slow AGC filter consists of a 330,000-ohm resistor and a 1.0 μf. capacitor. The capacitor, instead of being connected from the resistor to ground, is connected from the resistor to the output of a cathode-follower tube, which has a low-output impedance. This cathode-follower tube is fed by a tube that generates a voltage varying in magnitude with time. This is done in such a manner as to bias the two slow AGC i-f tubes to give low-receiver gain at the time the system transmits a pulse, and to increase the gain gradually with time in such a way that the echo signal from a target has a magnitude at the output of the receiver that is more or less independent of its range. This is called a sensitivity time control and reduces the amplitude of strong signals nearby so that it is easier to watch the desired signal at close range on intensity-modulated indicators.

The output of the long-time-constant filter is applied to the grid of a cathode-follower tube in order to obtain a low impedance for supplying the AGC voltage to the i-f amplifier grids. Since the grid of the tube is more negative than the cathode, it is necessary to tap down on the cathode resistor somewhat to make the d-c potential applied to the slow AGC i-f tubes the same as that applied to the fast ones. This tapping point is made adjustable to take care of variation between tubes. It is adjusted to give the same d-c output voltage at both slow and fast AGC output terminals.

Manual gain control is secured by switching the input of the fast AGC filter to a potentiometer, which furnishes the required variable voltage, manually controlled. Since the manually controlled voltage does not make use of the delay-bias diode, the diode-bias circuit must have an impedance that is low compared with the 1-megohm filter resistor in order to prevent change in maximum gain caused by the change in current in this diode circuit when switching from manual to automatic gain, or vice versa. When manual gain control is used, the long-time-constant filter resistor is shunted by a 47,000 ohm resistor to prevent sluggish action of the control.

RECEIVER POWER SUPPLY

One of the parts of an automatic-tracking radar system that requires careful consideration is the receiver power supply. Voltage of the a-c power-supply frequency or of its harmonics or subharmonics entering the system may modulate the signals or otherwise affect the direction-error signal. Such voltage could also result in the precision of the tracking of the target being impaired, and the antenna beam describing a circle about the target or even losing the target entirely.

Figure 6–14 shows the power supply for this fire-control radar receiver. It furnishes all a-c and d-c potentials used in the i-f amplifier-chassis part of the receiver. This includes

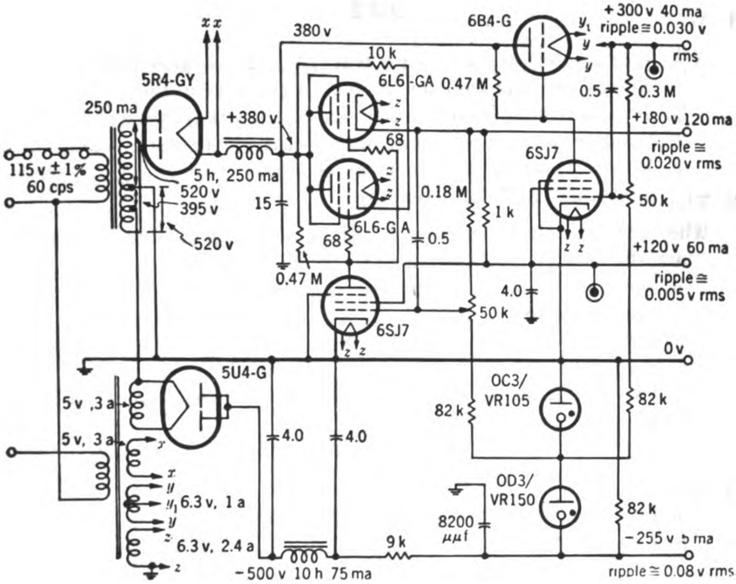


Figure 6–14.—Power supply.

the power for the i-f amplifier tubes, the second detector, the video tubes mounted on this chassis, the AGC circuit tubes, and the local oscillator. The voltages, currents, and ripple voltages are shown for the situation when the unit is operated from a good source of 60-cycle input, such as a commercial line fed by a central station.

To prevent low-frequency feedback in the amplifiers by the way of the power supply, electronic voltage regulators are used in this receiver, since filters for eliminating the low subharmonics are heavy and expensive.

QUIZ

1. Which of the following is NOT a feature of the balanced mixer?
   a. Signal crystals well matched into the waveguide.
   b. Transmitter harmonics attenuated by a polyiron attenuator.
   c. Good cross attenuation at only a narrow frequency band.
   d. Power reflected by the local oscillator and passed through more than 72 db of attenuation.

2. The AFC circuit illustrated in figure 6–2 will produce no spike when the carrier frequency is at 60 mc. because the
   a. outputs of the two halves of the discriminator will be equal and opposite.
   b. output circuit of tube *V2* will be tuned to the crossover frequency.
   c. two halves of the coupling network between tubes *V1* and *V2* will be overcoupled.
   d. discriminator curve will be straightened by loading resistors *R8* and *R9*.

3. What type of AFC circuit is shown in figure 6–2?
   a. D-c amplifier.
   b. Diode-phantastron.
   c. Gas tube.
   d. Thermal.

4. In the i-f circuit illustrated in figure 6–4, uniform response is obtained with small r-f changes because the
   a. loading across the tube input circuit is kept at a minimum.
   b. possibility of serious changes in the r-f elements is greatly reduced by the broad-band TR tube and balanced mixer.
   c. r-f input elements are closely coupled to the i-f input circuit by high-efficiency crystals.
   d. circuit has considerably more gain than other circuits less critical in tuning.

5. Compared with a single-tuned circuit, which of the following is an advantage of a double-tuned i-f circuit?
   a. It has a better overall gain-bandwidth product.
   b. It is more sensitive to capacitance variation.
   c. It requires adjustment when adjacent to transformers.
   d. It has a greater grid-circuit time constant.

6. The 6AK5 tube, rather than the 6AC7, is used as an i-f amplifier tube in double-tuned circuits because
   a. it permits a more critical circuit and thus greater gain per stage.
   b. it simplifies the obtaining of a wide bandwidth.
   c. it operates better at high frequencies.
   d. of all the above reasons.

7. A d-c restorer circuit is used in which of the following?
   a. Intensity-modulated cathode-ray indicators only.
   b. Both intensity-modulated cathode-ray indicators and AGC circuits.
   c. AGC circuits only.
   d. None of the above.

8. The amplifier for the tracking circuits are operated on the linear portion of the tube characteristic to
   a. retain the fidelity of signals.
   b. provides maximum possible gain.
   c. provide for negative feedback at low gain.
   d. increase the intensity of the c-w signal.

9. To select the desired signal in the third amplification stage of the receiver demodulator circuit, when is the gate applied to the screen grids?
   a. Immediately prior to the occurrence of the desired signal.
   b. Following the application of the gate to the suppressor grid.
   c. Coincident with the desired signal.
   d. One-half microsecond following the desired signal.

10. Which of the following is NOT a function of the demodulator circuit of the receiver?
   a. Providing AGC voltage for the receiver.
   b. Providing range video for the indicator amplifier.
   c. Providing controlling signals to operate the range servos.
   d. Providing controlling signals to operate the tracking servos.

11. The purpose of the pulse-stretching circuit of the receiver is to provide
   a. a voltage proportional to the peak voltage.
   b. a voltage approximately equal to the peak voltage.
   c. a voltage pulse which lasts long enough to charge a long time constant circuit using tubes of standard capacity.
   d. all of the above.

12. Which statement does NOT apply to the input circuit of the third amplification stage of the receiver demodulator circuit?
   a. All received signals and noise comprise the grid inputs of the gated tube.
   b. The coupling capacitor charges quickly through the d-c restorer diode and discharges slowly through a 160,000-ohm resistor.
   c. A moderately long time constant of 1,600 μsec. is used in the d-c restorer.
   d. The d-c restorer diode prevents the value of the gated tube input from being a function of noise.

13. In the range discriminator the two parts of the selected signal are recombined so that any difference between voltages will operate the
    - a. elevation servo circuit.
    - b. range servo circuit.
    - c. azimuth and elevation servo circuits.
    - d. azimuth servo circuit.

14. Which of the following statements does NOT apply to the switch tubes and the 0.001-μf.?
    - a. Capacitor can charge or discharge rapidly because the switch tubes are connected in the reverse direction.
    - b. Grid-leak resistors of 3.3 megohms are used so that the blocking oscillator will not determine the voltage of the 0.001-μf. capacitor.
    - c. The grids of the switch tubes are driven sufficiently negative to insure that these tubes are cut off during the gating period.
    - d. The switch tubes permit the 0.001-μf. capacitor to attain 95 percent of the possible value in approximately 3.0 μsec.

15. Why are electronic voltage regulators employed in the receiver power supply?
    - a. Filters for subharmonics of the 60-cycle power frequency are heavy.
    - b. Filters for subharmonics of the 60-cycle power frequency are expensive.
    - c. Regulators greatly reduce low-frequency feedback in the amplifiers with the power supply as part of the feedback path.
    - d. For all of the above reasons.

True—False

16. For manual gain control, a variable voltage from a potentiometer is applied to the input of the fast AGC filter.

17. The input to the AGC circuits is connected in series with the range-discriminator.

18. When the gates in the range-discriminator circuit are set at the correct range, the two parts of the selected signal have the same voltage.

19. To avoid false directional information resulting from transmitter pulling during the scanning cycle, the AFC circuits should be capable of acting fast enough to follow the transmitter.

20. AGC voltage is applied to the tubes of four amplifier stages—the third, fifth, sixth and tenth.

CHAPTER · 7

RADAR TIMERS

Circuits which control and synchronize the operation of the various components of radar equipment are known as TIMERS. The timing circuits are either assembled into a unit which constitutes a separate component of the equipment or they are contained within one or more components, such as the indicator, receiver, and control circuits.

TIMING SIGNALS

The signals required of the timing circuit depend largely upon the purpose of the set, the type of transmitter, and the method of data presentation. Typical requirements are illustrated in figure 7–1. This diagram does not necessarily apply to any particular set, but shows the more common timing pulse channels in general use in many systems. In figure 7–2 these timing pulses are shown in their proper time relationship.

Figure 7–2 represents the time-reference pulse originating in the timer circuit, and shows wave forms typical of externally synchronized systems. This figure is equally typical of self-synchronized systems in which the time-reference pulse is developed in the transmitter circuit. The time-reference pulse is used to trigger the various timing circuits into operation. Thus, in the case where the pulse originates in the timer circuit, the pulse shown in figure 7-2A becomes a transmitter trigger, and in the other case it becomes a timer trigger. In either case it serves as the reference point from which the other operations are timed.

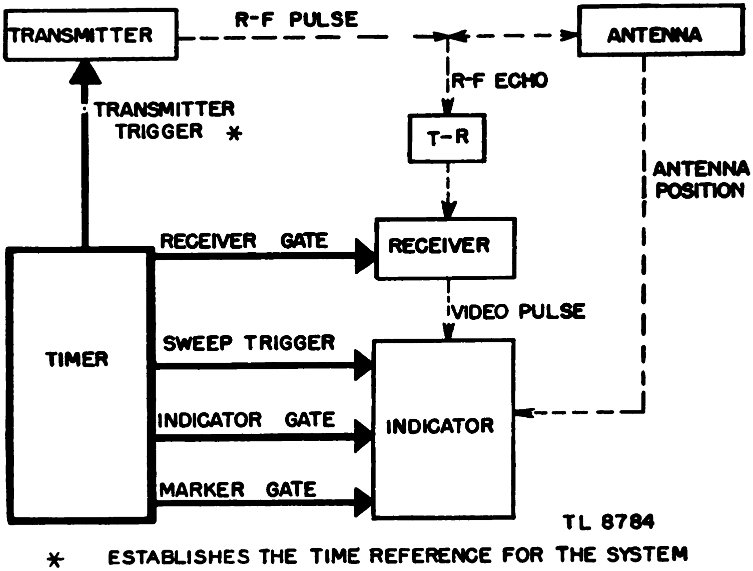


Figure 7–1.—Typical timing pulses of a radar timer.

The second timing pulse shown in figure 7–2C gates the receiver to make it operative during only the proper portion of the pulse cycle. It may be necessary to gate the receiver in this way in some sets in which short minimum ranges are important. The TR switch normally limits the amount of transmitter signal entering the receiver to a value which does not damage the crystal mixer, but it may not prevent blocking of the receiver circuits. When blocking occurs, the receiver remains inoperative for an interval immediately following the transmission of the pulse. This interval is required for recovery of the receiver to a state of normal sensitivity. If the plate and screen voltages of the first two or three i-f stages are removed during the transmitting time, receiver blocking is prevented and the minimum range at which targets can be detected becomes simply a function of the pulse width. The timing circuits are made to apply these screen and plate potentials in the form of a positive rectangular gate voltage during the time interval beginning just after the end of the transmitted pulse and ending after echoes are received from most distant targets in the operating range. Improvements in radar-receiver and TR switch design have shortened recovery time to such an extent that, in many sets, it is unnecessary to gate the receiver.

The timer also starts the range sweep in the indicator circuits. The timing pulse may be in the form of a trigger, as shown in figure 7–2D, where it occurs simultaneously with the transmitter trigger so that the beginning of the sweep and the beginning of the transmitter pulse coincide. If any appreciable delay occurs in starting the sweep in a cathode-

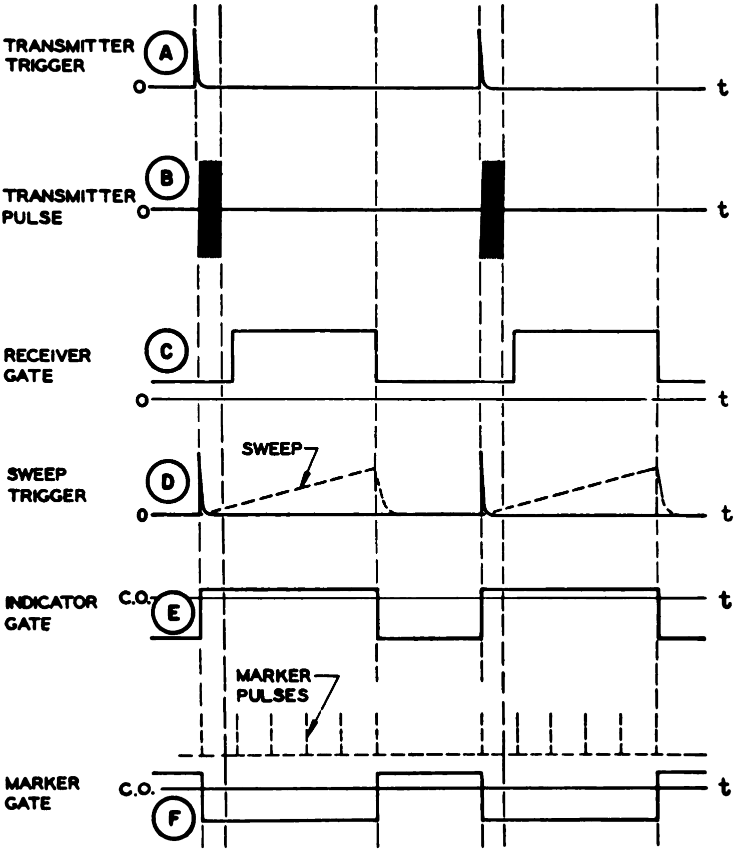


Figure 7–2.—Time relationship of pulses furnished by timer shown in figure 7–1.

ray tube which uses magnetic deflection, the sweep trigger may be made to precede the transmitter trigger to compensate for this inherent delay. The more commonly encountered alternative, however, is to trigger the sweep coincidently with the transmitter and develop a trapezoidal sweep voltage to overcome the delay.

If the tube remains in an operating condition during the entire pulse period, both the forward sweep and the return trace will be visible, so that signals appearing on the screen from targets outside the desired range will cause confusion in interpretation of echoes. To avoid this the circuits of the cathode-ray tube permit its operation to be controlled by a rectangular voltage, or gate. In figure 7–2E this gate is shown to be positive during the sweep time and is applied to the grid of the cathode-ray tube to reduce the bias sufficiently to make it operative. At the end of the sweep time the grid is returned to a high bias condition and signals returning during the remaining portion of the pulse period cannot appear on the oscilloscope. The same results are obtained by applying a negative gate to the cathode of the indicator tube during the sweep time.

The most commonly used method of estimating range directly on the indicator screen involves the production of range-marker pips in the indicator circuits and superimposing them on the video output of the receiver. The oscillatory circuit which generates the marker signals is gated by a rectangular pulse furnished by the timer, as shown in figure 7–2F. The marker gate enables the marker circuits to operate during the sweep time only and may be either positive or negative, depending on the input requirement of the marker generator.

To provide the required timing pulses, the timer must include the following:

(a) A circuit capable of establishing the pulse repetition frequency. This may be simply the grid circuit of an r-f blocking oscillator, a rotary spark-gap type of modulator, a sine-wave oscillator, a multivibrator, or a single-swing blocking oscillator.

(b) A means of forming the desired signals with the proper time relations. These may include such circuits as limiters, clampers, peakers, amplifiers, controlled multivibrators, and delay networks.

(c) Circuits designed to protect one component from the loading effect of another and to deliver pulses to the loads without distortion. Such circuits include the buffer amplifiers and cathode followers.

RANGE CIRCUITS

Fire-control range circuits are closely associated with the timing circuits for two principal reasons: (1) The need for precise range measurement, and (2) the number of gates timed by a trigger from the range circuits.

Figure 7–3 shows a block diagram of a range unit. The range channel sets the amount of delay and, hence, the amount of range by using an exponential rise of voltage to trigger a multivibrator circuit that forms the output range pulse.

START-STOP MULTIVIBRATOR

The function of the start-stop multivibrator of the range channel is to furnish a negative output pulse, the start of which coincides with the synchronizing pulse and the duration of which exceeds the time required for an echo to return from a target at maximum range. This function is performed by tube *V1*, which is connected so that it acts as a start-stop multivibrator. Figure 7–4 shows a schematic diagram of this circuit.

In the quiescent condition of the start-stop multivibrator, the first grid, pin 1 of this tube, is slightly positive with respect to its cathode, pin 3, because of positive voltage fed to the grid by the voltage divider consisting of *R1* and *R2*. The plate current drawn by this tube through plate resistor *R3* reduces the potential of the plate, pin 2, to about 30 volts above ground. The second grid of this double triode is connected directly to the first plate and, therefore, its potential

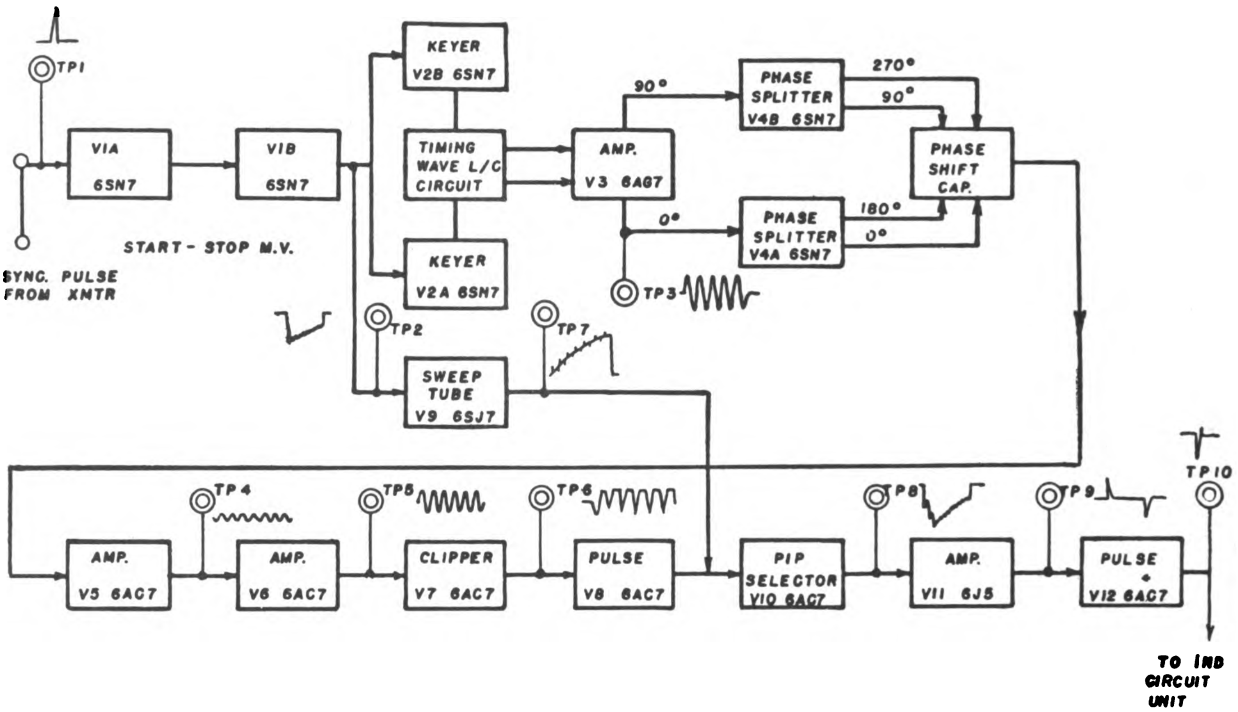


Figure 7–3.—Block diagram of a range unit.

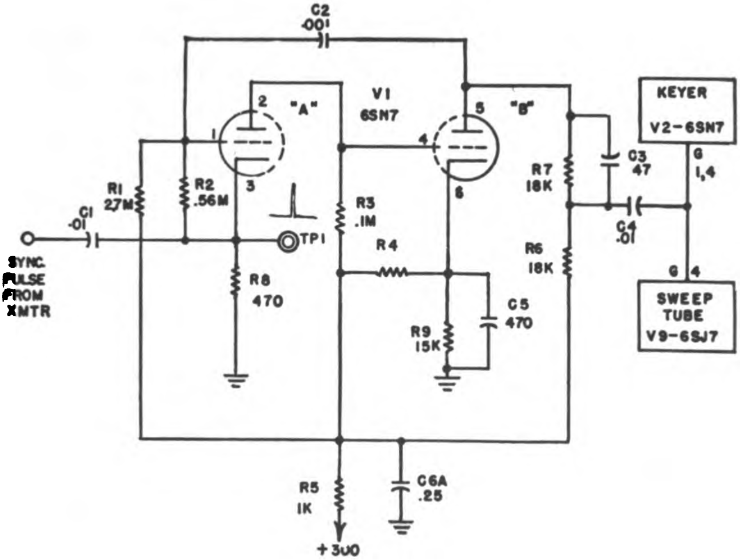


Figure 7–4.—Schematic diagram of the start-stop multivibrator.

is also 30 volts above ground. This tube is in a nonconducting condition because its cathode, pin 6, is held about 65 volts above ground by the voltage divider consisting of resistors *R4* and *R9*. Consequently, this section of the tube is completely cut off and its plate, pin 5, rests at approximately 290 volts above ground.

When a sufficiently large positive pulse is introduced at the cathode of *V1*, pin 3, the plate current of the first triode is cut off and its plate potential and that of the grid of the second-triode section rise with respect to ground. When the potential of the second grid passes the cutoff point of the second triode, its associated plate begins to draw plate current and the potential at this point begins to fall. This drop in potential is fed back to the grid of the first triode through capacitor *C2*, accelerating the rate at which the first triode cuts off and the second triode conducts. Consequently, a negative pulse with a very steep leading edge is produced at the plate of the second triode. The duration of this negative pulse depends on the time required for *C2* to discharge through resistors *R1* and *R2* in the grid circuit of the first triode. The values of these elements are chosen so that the negative pulse lasts longer than the time interval required for a signal to return from a target at maximum range. The actuating pulse and the output waveforms are shown in figure 7–5. You should remember that the input pulse and the leading edge of the output pulse occur at the same instant of time.

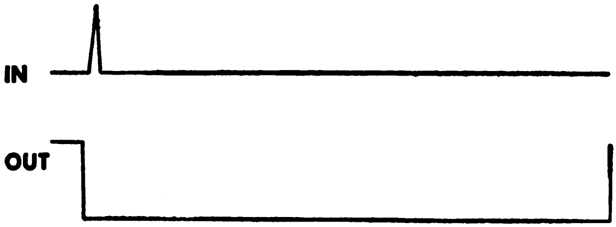


Figure 7–5.—Waveforms of the start-stop multivibrator.

RANGE CHANNEL

The function of the range channel is to introduce a time delay between the starting pulse that actuates the start-stop multivibrator and the range pulse from the range unit. The schematic diagram of the range channel, with representative waveforms at various points, is shown in figure 7–6. The channel consists of a switching tube, *V9*, which applies a voltage to *Z2;* a selector tube, *V10*, which is cut off until the voltage on the plate of *V9* reaches a predetermined value; and the start-stop multivibrator circuit, consisting of *V11* and *V12*, which is actuated by *V10*. The principle employed to obtain delay in this circuit is that time is required to build up the voltage across a capacitor when its charging current must flow through a resistance.

The quiescent condition of the tubes in this channel is as follows: *V9* has a positive voltage impressed on its grid through resistor *R53*, causing it to draw sufficient plate current through the resistor in the network, *Z2*, to reduce its plate voltage to almost ground potential; *V10* is cut off by

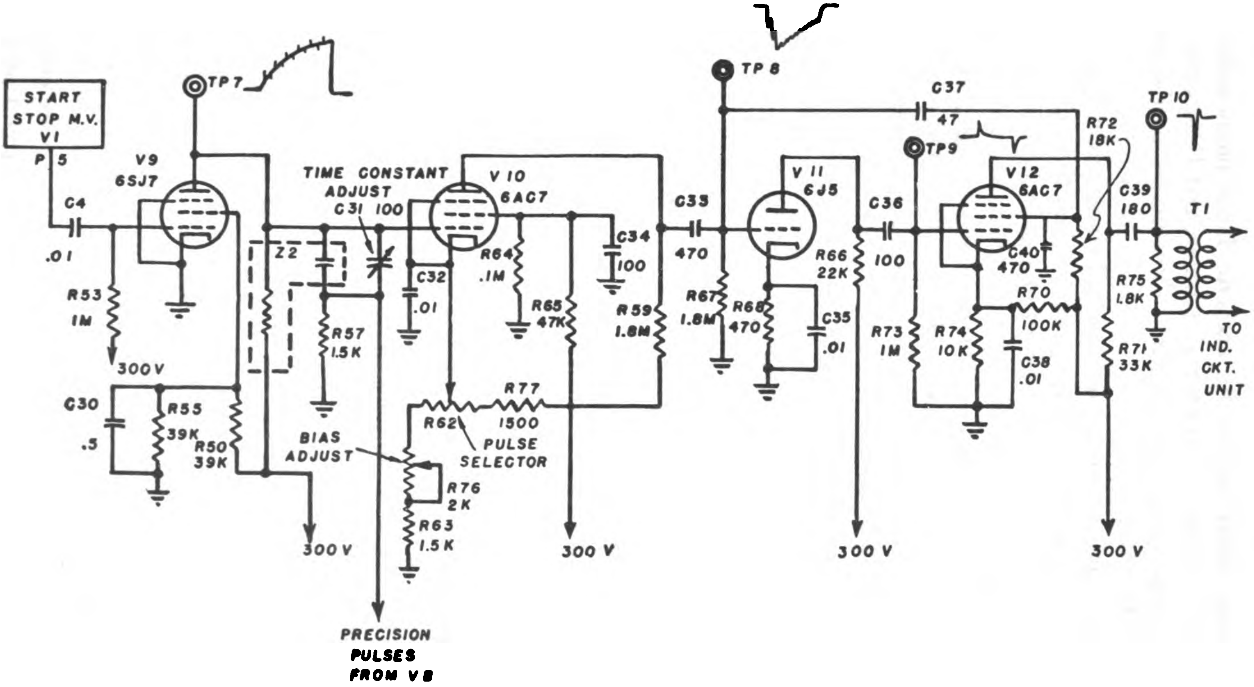


Figure 7–6.—Schematic diagram of the range channel.

the voltage impressed on its cathode from potentiometer *R62; V11* conducts in the normal manner, and *V12* is cut off by the voltage on its cathode from the voltage divider consisting of *R70* and *R74*.

The operation of the circuit is at all times under the control of the start-stop multivibrator. When the pulse from the transmitter causes the start-stop multivibrator, *V1*, to function, a negative voltage greatly in excess of that required to stop conduction in *V9* is applied to the grid of this tube through the action of *V1*. This negative pulse instantaneously cuts off the plate current of *V9* and keeps it cut off for the duration of the negative pulse. The potential at the junction of the plate of *V9* and the grid of *V10* at once begins to rise exponentially at a rate determined by the resistance in this network. The time constant of the network and of the associated adjustable air capacitor is approximately 700 microseconds. Accordingly, unless the charge is drained from the network-capacitor elements, it takes the capacitor 700 microseconds to charge up to about 63 percent of the plate-supply voltage applied to the network.

The potential at the grid of *V10* rises until it drives the grid positive with respect to its cathode and causes the grid to draw current and limit the rise of grid-circuit voltage. When its grid voltage rises above cutoff potential, the plate of *V10* draws current, causing its plate potential to drop sharply and to transmit a negative voltage to the grid of *V11*. This negative voltage causes the plate potentials of *V11* to rise and apply a positive voltage to the grid of *V12*. When the positive voltage on the grid of *V12* exceeds cutoff potential, its screen and plate potential drop sharply. A portion of the drop in screen potential is fed back through capacitor *C37* to the grid of *V11* so as to accelerate the action and completely cut off *V11*, thus driving *V12* to maximum conduction. The action of these two tubes is similar to that of the start-stop multivibrator, *V1*, except that in this case the feedback voltage is obtained from the screen circuit of the output tube rather than from its plate circuit.

The steep wavefront developed in the plate circuit of *V12* by the operation of *V11* and *V12* is differentiated by capacitor *C39* and resistor *R75* to form the output pulse. This pulse is passed through transformer *T1* to reduce the circuit impedance so that the pulse may pass over a transmission line without appreciably changing its wave shape.

The time interval between the synchronizing pulse to the start-stop multivibrator and the range pulse from *V12* is determined by the setting of potentiometer *R62*. The voltage build-up in the grid circuit of *V10* with respect to time is dependent only on the time constant of the network, *Z2*, and is an exact and duplicable function. Consequently, by an appropriate potentiometer design the delay introduced by this portion of the circuit can be made a linear function of the slider position of the potentiometer and, therefore, a linear function of the angular rotation of its shaft.

QUIZ

1. In the master-oscillator, the timer
   a. determines the pulse-repetition frequency.
   b. provides trigger pulses.
   c. provides gate pulses.
   d. performs all of the above.

2. The signals required of the timing circuit depend largely upon
   a. the purpose of the set.
   b. the type of transmitter.
   c. the method of presentation.
   d. all of the above.

3. The oscillatory circuit, which generates the marked signals, is gated by a
   a. saw-tooth pulse.
   b. sine wave.
   c. rectangular pulse.
   d. square wave.

4. To provide the required timing pulses, the timer must include which of the following?
   a. A circuit capable of establishing the pulse repetition frequency.
   b. A means of forming the desired signals with proper time relation.
   c. A circuit designed to protect one component from the loading effect of another.
   d. All of the above.

5. The pulse duration is determined by
   a. the size of the grid capacitor.
   b. the negative swing of the r-f oscillations.
   c. the pulse repetition frequency.
   d. none of the above.

6. The time interval between the synchronizing pulse to the start-stop multivibrator and the range pulse from *V12*, figure 7–6, is determined by the setting of
   a. capacitor *C31*.
   b. potentiometer *R62*.
   c. potentiometer *R76*.
   d. the bias on *V11*.

True—False

7. In the self-synchronous system, a sync pulse is taken from the transmitter to initiate the other trigger and gate pulses.

8. Desired pulse shapes and time relations may be produced by clipping and peaking the output of a sine-wave generator or blocking oscillator and multivibrators and delay lines.

9. The time-reference pulse is used to trigger the various timing circuits into position.

10. Range-marker pips are superimposed on the video output of the receiver to estimate range.

11. The transmitter trigger starts the range sweep in the indicator circuits.

12. Errors in range measurement and blurring of the target signals on the screen are caused by the direct timing of the system by the transmitter.

13. The blocking action of the r-f oscillator is controlled by its grid circuit.

14. The stability of the pulse rate is not affected by any change in the circuit constants.

15. The function of the range channel is to introduce a time delay between the starting pulses that actuate the stop-start multivibrator and the range pulse from the range unit.

CHAPTER 8

RADAR RANGE DATA

The accuracy with which the range of a target must be obtained varies with the tactical employment of the radar set. For example, range data for fire control must be accurate to within a few yards, while for a reporting station, the range data need be accurate only to within 2 or 3 percent of the range.

In applications of range data that require accurate measurement of range, some means is provided for introducing a variable delay to permit aligning the echoes with a reference mark. The reference mark may take the form of a hairline across the face of the oscilloscope, or of a notch or step in the sweep trace. In some cases the precision of measurement is improved by observing the desired echo on an expanded portion of the sweep.

RANGE ESTIMATION

METHODS OF ESTIMATION: To facilitate range estimation a given range can be represented by the total length of the sweep on the cathode-ray tube screen. If the transmitted pulse occurs at the beginning of the sweep, the range of a target may be estimated by observing the fraction of the sweep length between the transmitted pulse and the echo. Estimations of this kind depend on the judgment of the operator, and are made less accurate by any nonlinearity of the sweep.

If the radar equipment is installed in a permanent location, there may be a number of fixed targets whose ranges are known. Thus, several points on the sweep may be accurately calibrated, and the ranges of other echoes can be estimated with reference to these known points.

Estimation of range is made somewhat more accurate by the use of range markers which divide the trace into equal time intervals. Markers which appear on the sweep itself, rather than as marks on an overlaid scale, are preferable because they compensate for the effects of nonlinearity.

SHOCK-EXCITED OSCILLATOR: A circuit in which the plate current of a switch tube flows through the inductor of a tank circuit may be used to produce a damped train of oscillations by cutting off the tube. The frequency stability of this type oscillation is excellent. The tank circuit is very lightly loaded and the frequency depends in no way on the action of the tube. Such a circuit can be used to generate range markers which, in turn, make range estimation more accurate.

One system that is used for generating range markers from the output of a shock-excited oscillator is shown in figure 8–1. A negative-going square pulse drives the grid of *V1* below cutoff at the instant that the sweep starts, thus setting up oscillation in the tank circuit made up of *L1* and *C2*. Sharp, well-defined marker pulses are produced by feeding the output of the tank circuit through the remaining circuits of figure 8–1. The damped oscillations are limited and amplified by *V2* so that the output at the plate is a series of approximate square waves of the same amplitude.

Resistor *R2*, in series with the grid, limits the grid current and thus reduces damping effect on the *L–C* circuit. The cathode bias developed across *R3* and *C3* prevents the grid from going extremely positive, and thus aids in keeping the grid current low. A low-plate voltage is used to aid in the limiting action. The output of *V2* is coupled to the grid of *V3* which acts as an overdriven amplifier and produces a good square wave at its plate. The peaker-amplifier tube, *V4*, has as its plate load inductor *L2* shunted by resistor *R9*. The inductor resonates with its distributed capacitance at a frequency of the order of 2 megacycles per second.

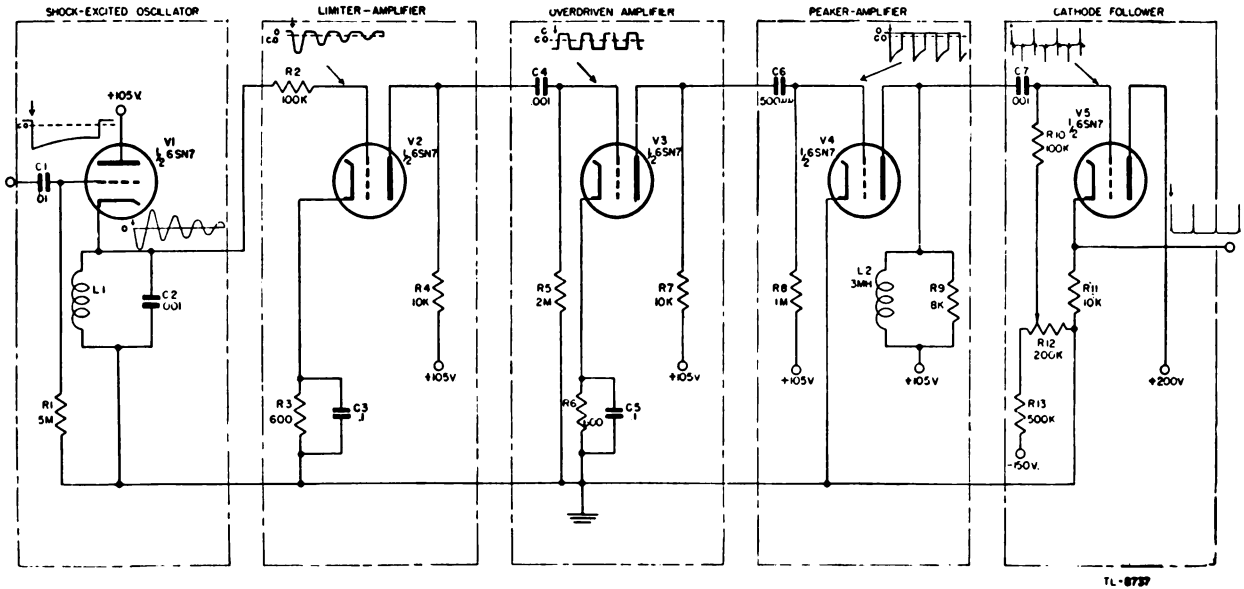


Figure 8–1.—Shock-excited oscillator used for producing range markers.

When the tube is cut off by the negative going square wave, the coil is shocked into oscillation. The resistance damps the oscillation almost completely before one cycle is completed, so that a positive pulse of approximately 0.25 microseconds duration is produced.

When the grid swings positive, a negative pulse of smaller amplitude appears at the plate. This has no significance, since the following tube is biased below cutoff so that only positive pulses affect its operation. The grid *V4* is returned to a positive potential, rather than to ground, in order to insure high conduction in the tube just before the grid swings negative. The large resistor, *R8*, in the grid circuit limits the grid current to a small value. The output of the pulse generator is fed to a cathode follower, which is biased below cutoff. By adjusting this bias so that the positive peaks raise the grid above cutoff by the desired amount, the amplitude of the marker pulses can be controlled.

If the oscillations in the cathode circuit of *V1* are damped too much to be used over the entire sweep, a regenerative circuit (fig. 8–2) can be used to sustain their amplitude. The

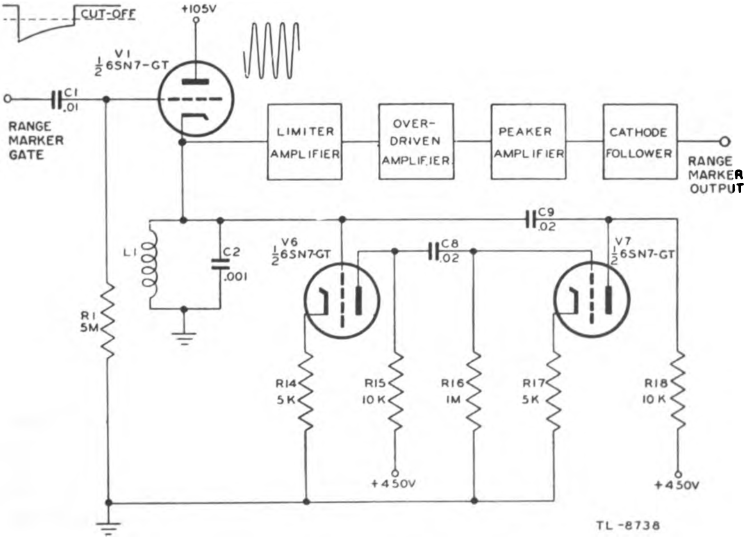


Figure 8–2.—Sustaining multivibrator.

circuits are identical with those of figure 8–1, with *V6* and *V7* added. The sustaining circuit is in the form of a multivibrator, with a natural frequency of oscillation much lower than that of the input signal. The output of the *L–C* circuit is coupled directly to the grid of *V6*, is amplified in *V6* and *V7*, and fed back to the input point in its original phase, having been inverted twice. The degeneration in the two unbypassed cathode resistors prevents excessive gain which would distort the sinusoidal wave generated in the *L–C* circuit. The frequency of oscillation is the resonant frequency of *L1–C2*, while the amplitude is held constant by the action of the multivibrator. When current flows in *V1*, the oscillations are damped out and start again when the current is cut off. The oscillations are used to generate positive marker pulses as discussed in connection with figure 8–1.

MULTIVIBRATOR

Range markers may also be generated by the type of multivibrator circuit shown in figure 8–3. The circuit is turned off and on by a signal applied through *C1* to the grid of *V1*. A negative pulse of relatively short duration cuts off *V1* and renders the circuit inoperative until the signal goes positive, at which time the sweep also starts. When *V1* begins to conduct, its plate voltage drops and causes the grid of *V2* to swing in the negative direction. The current through *V2*, and consequently the voltage at its cathode, decreases. This change, which takes place almost instantaneously, is coupled through *C3* to the cathode of *V1*, driving it in the negative direction. Since the grid of *V1* is held at a relatively constant voltage in respect to ground by the charge on *C1*, the effect of the voltage coupled through *C3* is to increase further the conduction of the tube. This cumulative action cuts off *V2* very quickly and drives *V1* into saturation.

The plate current of *V1* must flow through the three parallel branches in the cathode circuit of the tube. The current that flows in the branches in which there are capacitors causes a change in the charge of the capacitors by withdrawing electrons from one plate of each. This flow of current

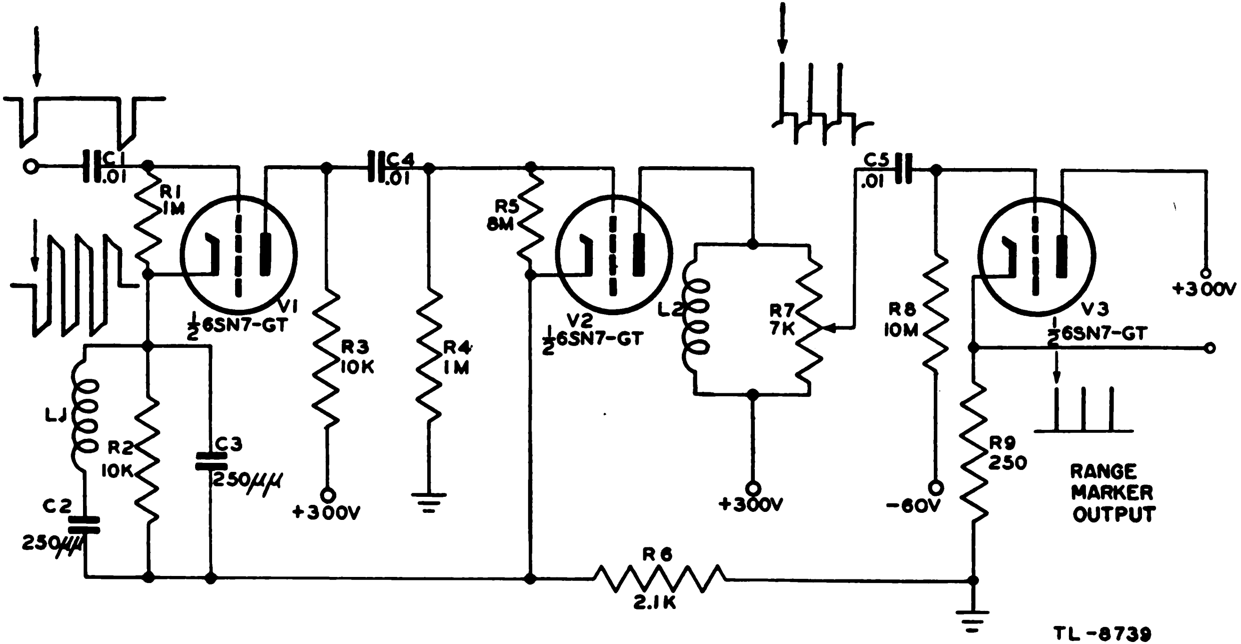


Figure 8—3.—Range marker multivibrator.

produces a voltage across the cathode impedance that drives the cathode positive, relative to ground. Since the three branches are in parallel, the voltage across each branch must always be the same. The change of voltage that occurs across the branch containing *L1* and *C2* controls the cathode potential because the rate of change of voltage in this branch is slower than in the others.

As the voltage rises at the cathode of *V1* its current becomes less and its plate voltage rises, causing the voltage at the grid of *V2* to rise. When the point is reached at which *V2* again conducts, a cumulative effect, which is the reverse of that previously described, cuts off *V1*. The tube remains cut off only during the time of one-half oscillation of *L1* and *C2*. At the end of this time the voltage across the tank circuit has swung to its maximum negative value, causing the start of a second cycle of the circuit action. Thus, *V1* and *V2* are made conducting alternately at a frequency determined by the values of *L1* and *C2*. Capacitor *C3* is used principally as a means of causing the change from conduction to nonconduction to be abrupt. Resistor *R2* is used to damp the oscillator circuit so that the stopping of oscillation may be controlled by the gate voltage applied to the grid of *V1*.

Since *V2* is cut on and off abruptly, sharp marker pulses can readily be produced in the plate circuit. The action of the plate load impedance is similar to that described in the peaker-amplifier of figure 8–1. Resistor *R7* is a potentiometer which provides a means of controlling the amplitude of the markers. The cathode follower is biased beyond the cutoff, so that only positive pulses appear in the output.

NEGATIVE TRANSCONDUCTANCE OSCILLATOR

One of the most stable of oscillators used to generate marker pulses is the negative transconductance oscillator, often called the transitron. Its stability compares favorably with that of a crystal-controlled oscillator with the exception that a steady drift over a long period of time is caused by aging of the oscillator tube. It has the added advantage that its operation can be controlled by a switch tube. A representative circuit for a negative transconductance range-marker system is shown in figure 8–4.

In figure 8–4 the plate current of switch tube *V1*, and the screen current of oscillator *V2*, flow through the inductor in the tank circuit made up of *L1*, *C3*, and *C4*. When the switch tube is cut off, the current in *L1* tends to change abruptly, causing the magnetic field around *L1* to start to collapse. This collapsing magnetic field induces in the inductor a voltage which drives the screen grid of *V2* positive. The voltage induced in *L1* sets up oscillations in the tank circuit that are maintained by the action of *V2*. If the bias on *V1* is adjusted to give the proper current through *L1*, the amplitude of the first cycle of the oscillation in the tank circuit can be made equal to the steady state amplitude. When the switch tube is again made conducting, the tank circuit is effectively shunted by a low resistance and oscillations are quickly damped out. Thus, application of a negative gate voltage to the grid of *V1* controls the length of time during which oscillations are generated, and insures that the first alternation is always a positive-going half-sine wave which starts at the leading edge of the gate voltage.

The output of the transitron oscillator is fed into a cathode follower because this type of circuit provides the high impedance necessary to avoid loading the oscillator. Since the cathode follower is biased, the output is a series of half-sine waves which are used as range markers in some applications. The cathode follower in some cases may feed conventional squaring amplifiers and peakers to produce sharp marker pulses.

RANGE MEASUREMENT

The difficult problem of firing a gun accurately can be simplified considerably if the EXACT distance between gun and target can be determined. Radar provides a means of finding this distance by measuring the time required for r-f energy to travel out to a target, be reflected, and return. Precise measurement of range requires the accurate measurement of extremely short time intervals. These intervals are

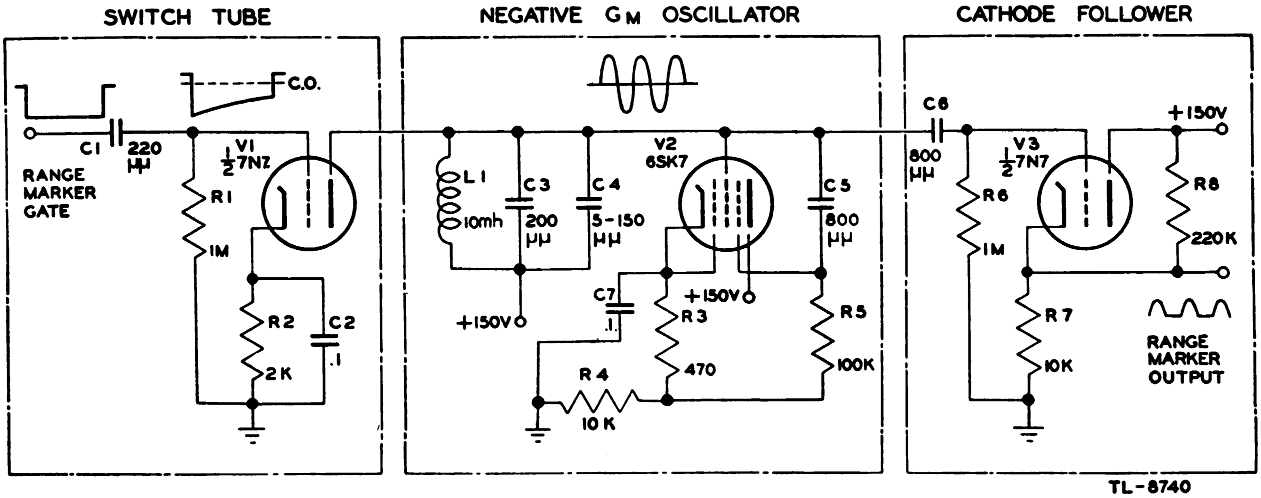


Figure 8–4.—Negative transconductance oscillator, range marker circuit.

measured by some means of introducing an accurately calibrated variable delay between the transmitted pulse and the echo pulses on the indicator screen.

Several methods of producing a variable delay to measure range are in use in existing radar equipment. One commonly used method is to shift the phase of the sine wave which times the indicator relative to the sine wave which times the transmitter. The phase shift is used to delay the action of some circuit in the indicator by a measured number of electrical degrees, and therefore to measure the time in terms of the period of one cycle of the sine wave. The phase-shifting device usually is geared to a dial, which is calibrated in yards or other suitable units of range.

The range of a target may also be measured by the use of a circuit which measures the magnitude of the sweep voltage at the position at which the echo pulse appears on the sweep. This method depends on the comparison of the sweep voltage with a calibrated variable d-c voltage, and it is inherently not as accurate as most phase-shifting methods. However, it does find considerable use in search radar sets in which it is desired to measure range to a fair degree of precision.

Other methods of measuring range include the use of a delay multivibrator, an acoustic tank employing a fixed and a movable crystal, and calibrated control of the position of the sweep relative to a fixed marker on the face of the indicator.

METHODS OF OBTAINING PHASE SHIFT

The voltage obtained from a phase shifter should be of constant amplitude at all phases to produce uniform operation of the circuits which follow. In order to make accurate measurement, one degree of rotation of the phase shifter should produce a change in phase of one electrical degree or less. The Helmholtz coil is a commonly used device for satisfying these requirements.

Another type of phase shifter using a special capacitor is also satisfactory. See figure 8–5. In this circuit the reactance of capacitor *C1* or *C2* at the operating frequency of 4.1 kilocycles per second is 4,314 ohms. The resistance of

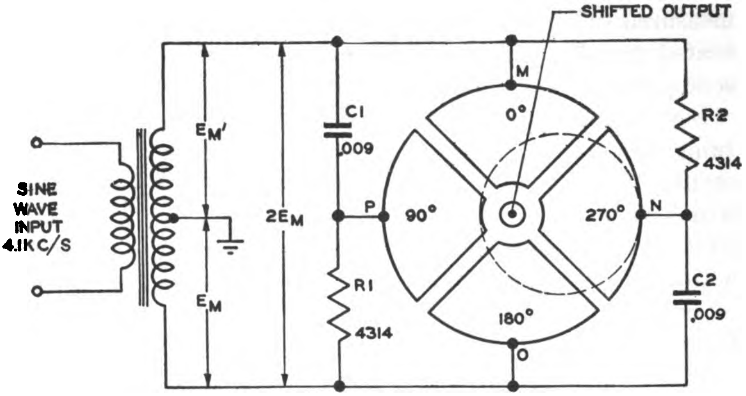


Figure 8–5.—Phase-shifting circuit for producing a 360° phase shift.

both *R1* and *R2* is made equal to this value. The current through either *R1–C1* or *R2–C2* leads the voltage across the transformer secondary by 45°. The voltage across either resistor is in phase with the current, and therefore leads the transformer voltage by 45°. The voltage across either capacitor lags the current by 90°, and therefore lags the transformer by 45°. If the series impedance of R and C is given by $Z=\sqrt{R^2+X^2}$, and $Xc=R$, then $Z=\sqrt{R^2+R^2}=R\sqrt{2}$. Therefore, the amplitude of the voltage across a resistor or a capacitor is

$$Er=Ec=\frac{R}{Z}\times 2Em=\frac{R}{R\sqrt{2}}\times 2Em=Em\sqrt{2}$$

where $2Em$ is the voltage across the transformer, or Em is the voltage from M to ground. If Em is taken as the reference in the vector diagram (fig. 8–6), Er leads Em by 45°, and Ec lags Em by 45°. The voltage Ep, measured from P to ground, is the vector difference, $Em-Ecl$. This difference is found by taking $-Ecl$ as a vector equal in magnitude to Ecl but opposite in direction, and completing the parallelogram with Em. The voltage Ep leads Em by 90° and has the same amplitude. Likewise the voltage En, which is measured from N to ground, is the vector difference $En-Er$. It is equal in magnitude to Em and lags Em by 90°. The voltage Eo, from O to ground, is 180° out of phase with Em, but equal in magnitude since the two points are at opposite ends of a transformer whose center tap is grounded.

Thus, four voltages at 90° intervals in phase are supplied to the four stator sections of the phase-shifting capacitor. The rotor plate picks up voltage components from two or three stator sections simultaneously. The voltage at the output is the vector sum of these components. In the position shown in figure 8–5, the components from plates *M* and *O* cancel each other because they are equal in magnitude and 180° out of phase. Consequently, the output is 270° out of phase with the transformer voltage. The plates are shaped so that the output is of constant amplitude, and so that rotation through one degree mechanically changes the output phase one electrical degree.

A modification of this phase shifter uses voltages from the plates and cathodes of two vacuum tubes, fed 90° out of phase, to supply the excitation for the four stator plates. In addition, a stationary output plate which meshes equally with all stators may be used. The phase shift is then produced by rotating a dielectric plate, which varies the capacitive coupling between the output plate and the four energized sections.

The accuracy with which ranges can be measured by phase-shifting methods depends on the device used. In extreme cases the error of the phase shifter may be several electrical

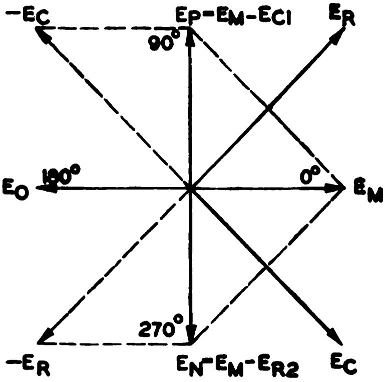


Figure 8–6.—Vector diagram of phase-shifting circuit.

degrees. The time error resulting from inaccurate phase shifting may be reduced by making the frequency of the sine wave high, so that one electrical degree represents an extremely short time. This requires a means of counting or selecting cycles as well as a means of producing an accurate phase shift.

GENERATION OF FIXED RANGE MARKERS BY PHASE SHIFT

In many applications the phase shift is used to control the starting time of the sweep so that, as the phase of the timing voltage to the indicator is changed, the transmitted pulse and echoes appear to move along the sweep. Some marker at a fixed position on the sweep is used as a reference. The marker may be a hairline on the face of the cathode-ray tube, or a step or notch generated at a fixed time after the beginning of the sweep.

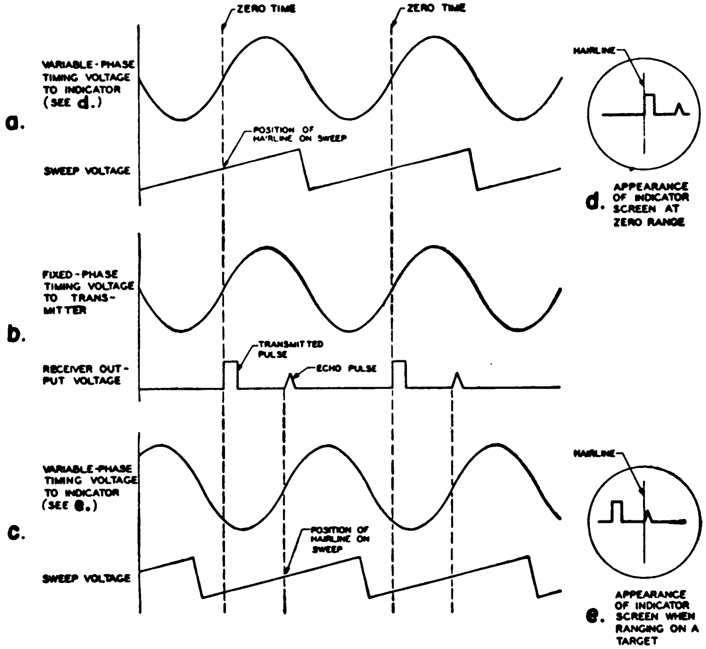

ZERO TIME
ZERO TIME
VARIABLE-PHASE TIMING VOLTAGE TO INDICATOR (SEE d.)
a.
POSITION OF HAIRLINE ON SWEEP
SWEEP VOLTAGE
HAIRLINE
d.
APPEARANCE OF INDICATOR SCREEN AT ZERO RANGE
FIXED-PHASE TIMING VOLTAGE TO TRANSMITTER
b.
TRANSMITTED PULSE
ECHO PULSE
RECEIVER OUTPUT VOLTAGE
VARIABLE-PHASE TIMING VOLTAGE TO INDICATOR (SEE e.)
c.
POSITION OF HAIRLINE ON SWEEP
SWEEP VOLTAGE
HAIRLINE
e.
APPEARANCE OF INDICATOR SCREEN WHEN RANGING ON A TARGET

Figure 8–7.—Sweep timed by phase shift.

In figure 8–7b the timing sine wave to the transmitter, and the phase of the transmitted pulse and echo relative to this sine wave, are shown. If the phase shifter is set to zero range, the phase of the indicator timing sine wave and the phase of the sweep voltage relative to the transmitted pulse, are shown in figure 8–7a. The indicator is designed so that a hairline on the screen always appears in the middle of the sweep trace. Thus, the appearance of the indicator screen at zero range of an echo is shown in figure 8–7d. However, if it is desired to find the range of an echo, the phase of the indicator timing sine wave must be changed so that the sweep starts before the transmitted pulse is sent out. Thus, if the indicator timing voltage is made to lead the transmitter timing voltage by the amount shown in figure 8–7c, the echo will appear at the reference hairline as in figure 8–7e. Note that the transmitted pulse and echo have moved across the screen, but that the sweep still occupies the same space on the screen.

Some radar equipments use a phase shift of two different frequencies to improve the accuracy of range measurement. The master oscillator of the timer in such a system generates a sine wave which is applied to a phase shifter to time the indicator, and from which a modulation pulse is generated to operate the transmitter. A highly selective filter selects a voltage of one of the harmonic frequencies of which the pulse is composed, and this voltage is also fed to the indicator through a phase shifter. If the 18th harmonic is selected, one cycle of the harmonic is equal in time to 20 electrical degrees of the repetition frequency. The two-phase shifter must be geared in an 18 to 1 ratio, so that the shift at the harmonic frequency is 18 times as great as that at the fundamental in order to measure the same time interval.

In the circuits following the phase shifters, the fundamental voltage is squared and peaked; the harmonic voltage is limited, amplified, and differentiated until only narrow peaks appear. The peaking circuit of the fundamental is a push-pull arrangement whereby two peaked-voltage wave forms, one the inverse of the other, are obtained.

A circuit which uses these voltages to produce both a sweep trigger and a reference marker notch whose phase is always such that it appears in the center of the sweep is shown in figure 8–8. The peaks of the harmonic frequency are applied to the grid of *V1*, and the peaked wave forms of the fundamental frequency are produced by the short time constant *R–C* circuit consisting of *R2*, *C2* and *R3*, *C3*. The resistors *R4* and *R5*, in series with the grids of *V2* and *V3*, limit the swing of the grids in the positive direction. The duration of the peaks from the fundamental is such that one and only one of the peaks from the harmonic frequency can occur during this time. At the time indicated by the arrows on the wave forms, the current in *V2* is reduced greatly, while that in *V3* is increased slightly. The total current through the two tubes, and therefore the voltage drop across

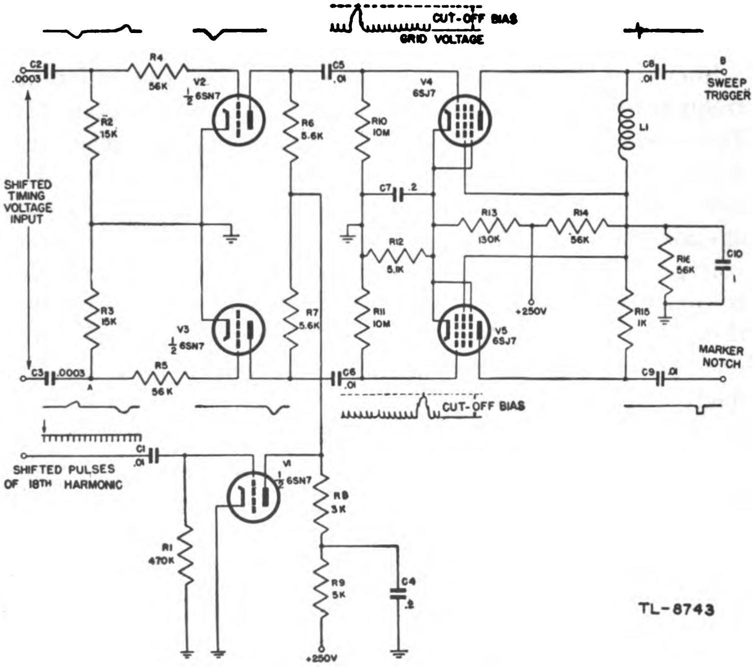


Figure 8–8.—Circuit for producing fixed-phase reference notch.

R8, are reduced. The voltage drop across *R6* is reduced, while that across *R7* is increased. The two effects in *R6* and *R8* are in the same direction and therefore add, while in *R7* and *R8* they are opposite and tend to cancel each other. The result is a definite positive pulse at the plate of *V2*, and perhaps a slightly positive pulse at the plate of *V3*.

The reduced current in *V1*, caused by the negative pulses on its grid, flows through *R8* and produces positive pulses at the plates of both *V2* and *V3* so that the fundamental and harmonic voltages are mixed. When the polarity of the pulses on the grids of *V2* and *V3* is reversed a half cycle of the repetition frequency later, the previously described action of the tubes is reversed. The resulting wave form at each plate is a series of pulses, recurring at the rate of the harmonic frequency, with every 18th pulse on top of a pedestal. The two pedestal voltages are 180° out of phase with each other since one occurs at the positive peak and the other at the negative peak of the fundamental sine wave.

Note that the time constant of the coupling circuits into *V4* and*V5* is extremely long. The grid leak bias produced in these coupling circuits, combined with the cathode bias produced across *C7* and *R2*, permits only the pulses which are on the pedestals to cause conduction. The plate load of *V4* is an inductor which is shocked into oscillation with its distributed capacitance when the tube is suddenly made conducting. The indicator is used because a positive trigger pulse is required for the thyratron sweep generator which follows. The positive pulse is obtained from the second swing of the oscillation, so that the use of a phase inverter tube is avoided. The slight delay introduced by this method is compensated for in the zero adjustment of the phase shifter. The output of *V5* is a negative notch voltage which is applied to a vertical deflecting plate of a cathode-ray tube as a marker.

Since the marker is always generated one-half cycle of the fundamental after the generation of the sweep trigger, it appears stationary on the screen as the phase of the sine-wave timing voltage is changed.

GENERATION OF MOVABLE RANGE MARKERS BY PHASE SHIFT

In some methods of measuring range a marker is produced which is moved along the sweep to the position of the echo whose range is desired. The control which causes this motion is calibrated directly in yards, so that the range may be read from the setting of the control. Where a phase-shifting method is used to produce the marker, the transmitted pulse and the sweep are timed from the same sine wave. The phase of these voltages relative to the timing sine wave is shown in figure 8–9a. The timing sine wave is also applied through a phase shifter to a range-mark generator. The range mark, shown as a notch in figure 8–9, is gen-

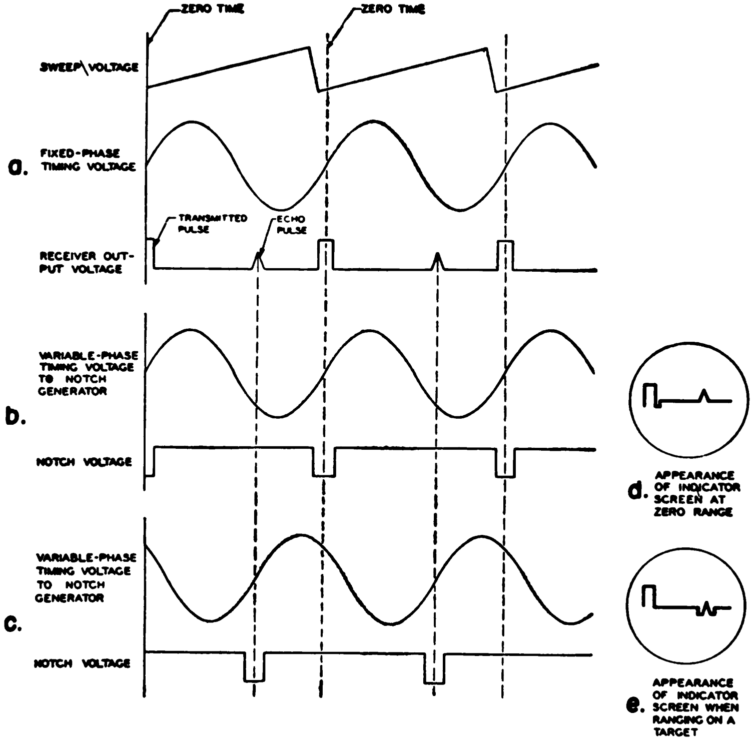

ZERO TIME
ZERO TIME
SWEEP VOLTAGE
a.
FIXED-PHASE TIMING VOLTAGE
TRANSMITTED PULSE
ECHO PULSE
RECEIVER OUTPUT VOLTAGE
b.
VARIABLE-PHASE TIMING VOLTAGE TO NOTCH GENERATOR
NOTCH VOLTAGE
c.
VARIABLE-PHASE TIMING VOLTAGE TO NOTCH GENERATOR
NOTCH VOLTAGE
d. APPEARANCE OF INDICATOR SCREEN AT ZERO RANGE
e. APPEARANCE OF INDICATOR SCREEN WHEN RANGING ON A TARGET

Figure 8–9.—Movable marker timed by phase shift.

erated at some fixed phase of the phase-shifter output in figure 8–9b. When the phase shifter is adjusted to the zero-range position, the notch voltage has the phase relative to the sweep shown in figure 8–9b, producing a picture on the indicator screen like that in figure 8–9d. When it is desired to range on a target, the phase of the voltage to the notch generator is shifted as in figure 8–9c, so that the notch moves along the sweep to the position of the echo. When the echo is centered in the notch, as in figure 8–9e, the range may be read from the calibrated dial.

In many radar systems the timer does not produce a sine wave. However, advantage may be taken of the methods by using the circuit shown in block form in figure 8–10a. The timing pulse from the transmitter, figure 8–10b(A), controls the operation of a one-shot multivibrator, which produces a square-wave output, figure 8–10b(B). During the negative portion of this square wave a timing wave, figure 8–10b(C), is generated by a shock-excited oscillator tuned to 81.955 kilocycles. This sine wave is applied to a phase shifter of the type described under Methods of Obtaining Phase Shift. The shifted output, figure 8–10b(D), is amplified and differentiated to form a train of sharp positive and negative pulses, figure 8–10b(F). These pulses are combined with a sawtooth voltage in a pulse-selector circuit, figure 8–10b(G). By varying the cathode potential in this circuit, the cutoff point may be shifted to select any of the positive pulses to produce a single output marker, figure 8–10b(H).

The schematic circuit diagram of the pulse selector is shown in figure 8–11. Here the voltage drop across *V1* is very small in the absence of an applied signal, because the grid is connected through *R1* to *B+*. The negative swing of the one-shot multivibrator cuts off *V1* for the duration of the sweep, allowing capacitors *C3* and *C4* to charge through *R2* and *R3*, toward +300 volts. The timing pulses produce a voltage across *R3* which is in series with the sawtooth voltage developed across the capacitors, so that the sum of these two voltages appears at the grid of *V2*. The bias on this tube is controlled by potentiometer *R6*, so that *V2* cannot

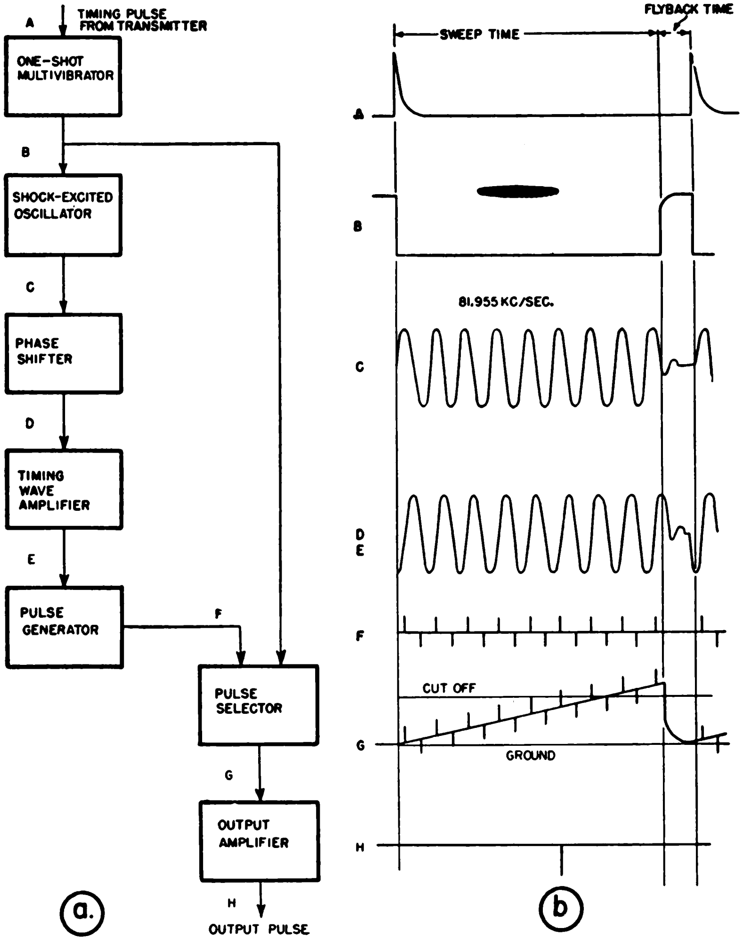


Figure 8–10.—Block diagram of method of producing movable range mark by phase shift.

conduct until the grid voltage rises above cutoff. The first timing pulse, which drives the grid above cutoff, causes a sharp drop in voltage to take place at the plate of *V2*. If only *R6* is varied, tube *V2* will be made to conduct at intervals corresponding to 2,000 yards of range, because the frequency of the timing voltage was made 81.955 kilocycles per second. However, since the phase of the timing voltage is varied, a smooth variation in the time at which *V2* begins to conduct

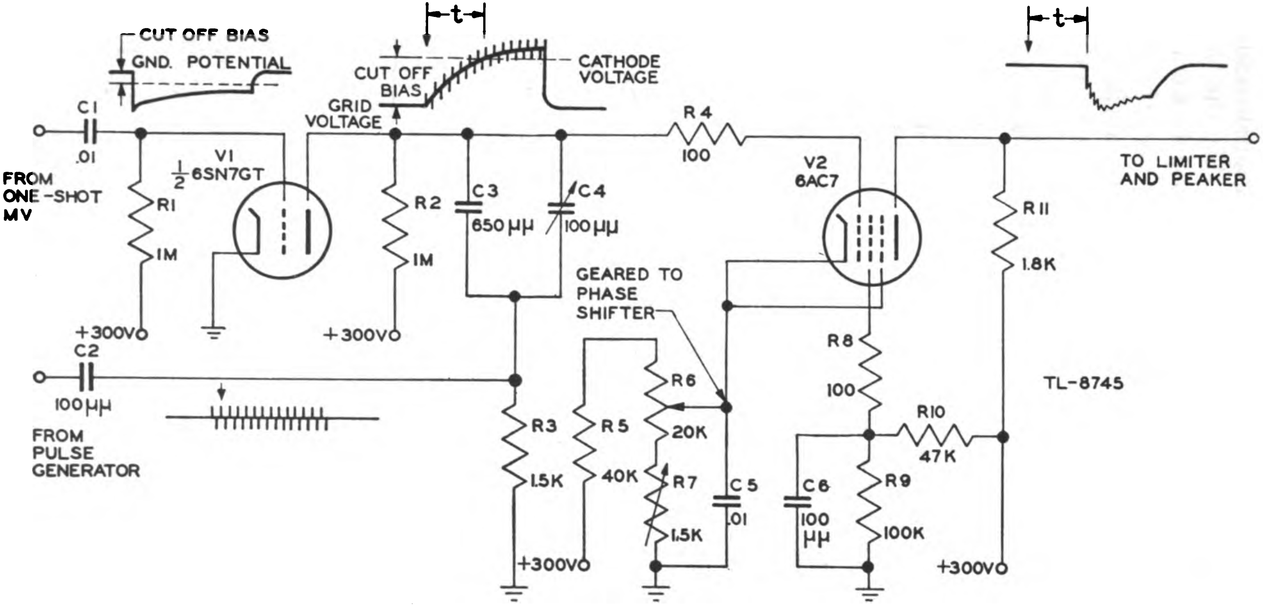


Figure 8–11.—Circuit diagram of pulse selector.

can be obtained if potentiometer *R6* is geared to the phase shifter, while the phase is changed, so that the pulse one step farther up or down the slope causes conduction.

The range marker is generated at the time that *V2* first conducts. Thus the combination of phase shifter and potentiometer measures the interval between the transmitted pulse and the marker. The accuracy of this measurement is improved by tapering potentiometer *R6* to compensate for the nonlinearity of the sawtooth voltage generated by *V1*.

The type of circuit discussed under Generation of Fixed Range Markers by Phase Shift may be adapted to the generation of a movable range marker by the use of the circuit shown in figure 8–12. The timing sine wave for the radar system and the fortieth harmonic of the timing frequency are each fed to phase shifters, which are geared together in a 40 to 1 ratio. The fundamental is used to produce a pedestal voltage, and the harmonic voltage is converted into a series of sharp positive and negative pulses. These voltages are capacitively coupled to the grid of a tube, which is biased so that only the pulse on the pedestal can cause conduction.

Capacitor *C4* is discharged through *V1* during the time that the pulse makes the tube conduct. After the pulse passes, *C4* charges again to +300 volts through *R6*. The wave form produced is in the form of a step, which is applied to a

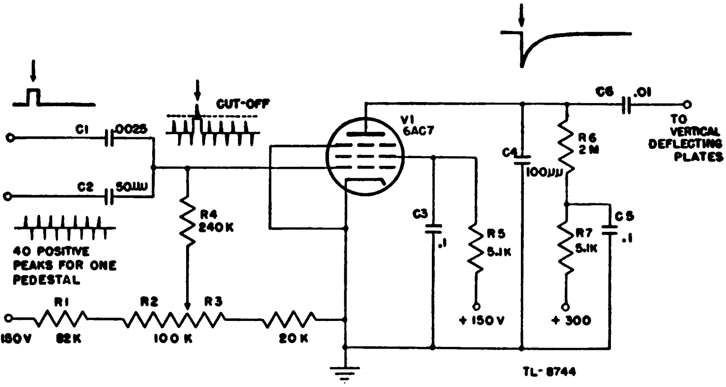


Figure 8–12.—Circuit for producing movable range marker by phase shift.

vertical deflecting plate as a range marker (fig. 8–14). The height of the step may be controlled by adjusting the bias on *V1* to vary the effective resistance of the tube during the conducting time. The sweep is always started at the time of the transmitted pulse so that the step moves as the pulse shifters are turned.

GENERATION OF MOVABLE RANGE MARKER FROM SWEEP VOLTAGE

A circuit which uses the sweep voltage to produce a time delay for the generation of a range marker is shown in figure 8–13. The sweep voltage shown in figure 8–13 (A) is coupled directly from the sweep generator to the grid of *V1*. This tube is operated as a biased cathode follower, the bias being supplied by the voltage divider consisting of *R2*, *R3*, and *R4*. The bias is adjusted, by means of *R3*, to cause the tube to begin conducting at any instant from the beginning to the end of the sweep. The duration of the sweep is indicated as "S" in the wave forms and the variable interval between the start of the sweep and the start of conduction in *V1* is shown as "t."

The voltage at the cathode of *V1* (fig. 8–13 (B)) remains constant at the level selected by delay control *R3* until the instant when the sweep voltage drives the grid more positive than cutoff. At this time the cathode voltage begins to rise at the same rate as the sweep voltage. The cathode voltage is coupled out through *C2* and *R5* to a differentiating circuit consisting principally of *C4* and *R6*. The linear rise of voltage that takes place, starting at time "t" (fig. 8–13 (C)), causes a sudden rise of voltage (D) in the output of the differentiating circuit. This sudden rise is amplified by *V2* and the resulting wave form (E) is applied to a vertical deflecting plate of a cathode-ray tube to serve as a range marker. The indicator screen has the appearance shown in figure 8–14. The range is measured by varying *R3* until the step coincides with the left-hand edge of the desired echo. The shaft of *R3* is geared to an indicator on which the range is shown in yards or miles.

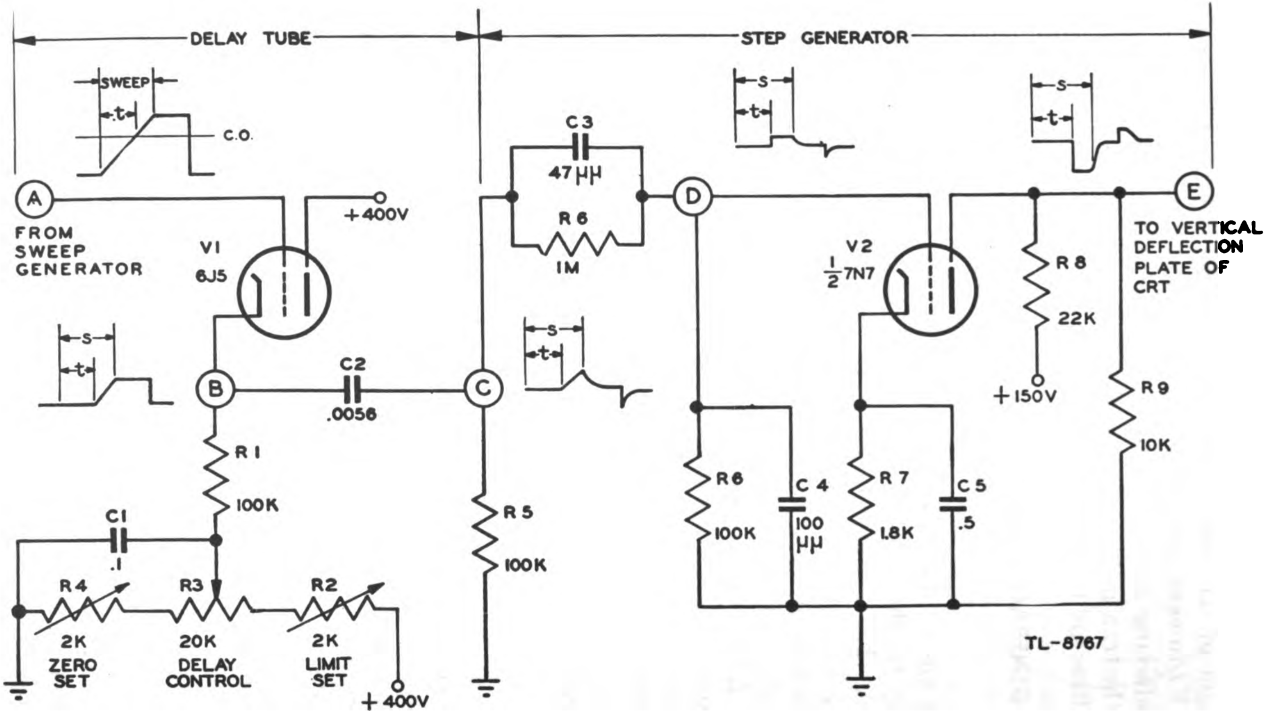
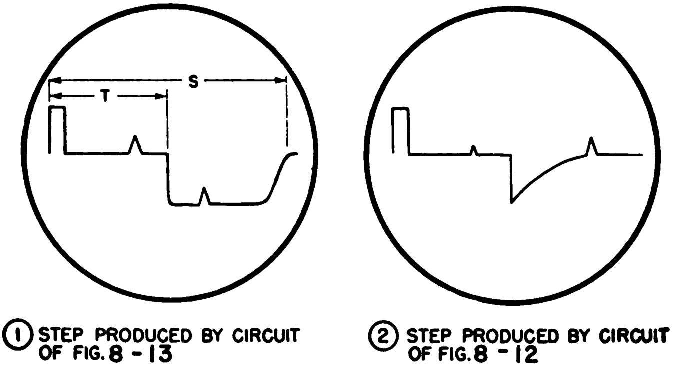


Figure 8-13.—Circuit for generation of movable marker from sweep voltage.



① STEP PRODUCED BY CIRCUIT OF FIG. 8 - 13

② STEP PRODUCED BY CIRCUIT OF FIG. 8 - 12

Figure 8–14.—Range marker steps.

The accuracy of the delay control may be checked by applying it to the sweep range markers, such as those discussed under Generation of Movable Range Markers by Phase Shift. After the speed of the sweep is adjusted to the proper value, the delay control may be adjusted by variation of *R2* and *R4* to compensate for slight nonlinearity of the sweep.

GENERATION OF MOVABLE RANGE MARKER BY DELAY MULTIVIBRATOR

A one-shot multivibrator which can be used to provide a variable delay for the measurement of range is shown in figure 8–15. In the resting state *V1* is conducting, while *V2* is cut off by the bias provided by the voltage divider made up of *R3* and *R4*. Since the grid of *V1* is returned to the plate of *V2*, it tends to be positive. A charge on *C2*, resulting from grid current, holds the grid of *V1* essentially at ground potential, and the grid current of this tube is limited to an average value of less than half a millampere by resistors *R2* and *R6*. A negative pulse, generated at the time of the transmitted pulse, is applied through *C1* to the grid of *V1*. The multivibrator action causes *V2* to conduct and drives the grid of *V1* below cutoff, and the charge on *C2* begins immediately to leak off through *R2*. As a result of this leakage, the potential at the grid of *V1* returns toward that at the plate of

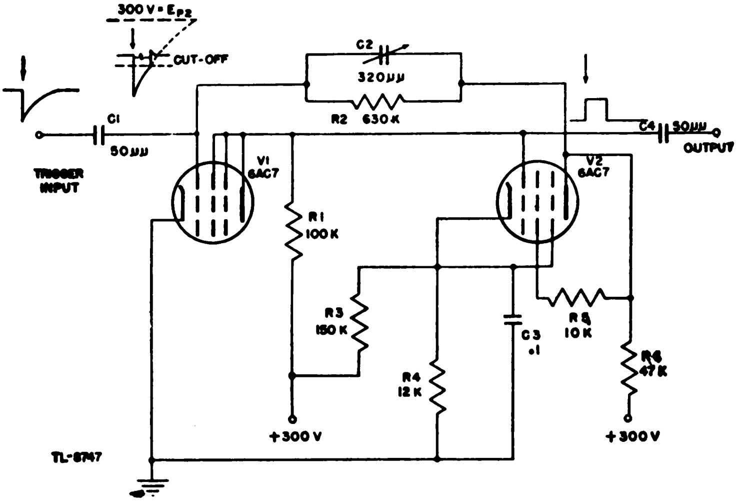


Figure 8–15.—Delay multivibrator.

V2 at an exponential rate which depends on the time constant, *R2 C2*. When the potential at the grid reaches such a value that *V1* again conducts, *V2* is cut off, *C2* is charged quickly to its normal voltage by grid current, and the circuit is returned to its normal resting state until another negative pulse is applied. The output, a positive pulse taken from the plate of *V1*, is differentiated, and the pulse from the trailing edge is used as a range marker. Thus a time delay, equal to the width in microseconds of the pulse from the multivibrator, is produced. The width of this pulse is controlled by varying *C2*. The control is made more accurate by returning the grid of *V1* to a positive potential, rather than to ground, causing the grid-potential curve to have a steeper slope at its point of intersection with the cutoff line. The shaft of *C2* is geared to a dial calibrated to indicate range.

QUIZ

1. At the instant that the sweep starts, the grid of *V1*, figure 8–1, is driven below cutoff by a
   a. sawtooth wave.
   b. negative-going square wave.
   c. positive-going square wave.
   d. none of the above.
2. *V4*, figure 8–1, has as its plate load
   a. *C6* and *R8*.
   b. *L2* and *R9*.
   c. *C7*, *R10* and *R12*.
   d. *V5*.
3. In the multivibrator circuit shown in figure 8–3, *V1* is turned on and off by
   a. the signal applied through *C1* to the grid.
   b. the drop across *R1*.
   c. the action of *L1*, *R2* and *C3*.
   d. *C4 and R3*.
4. Movable range markers are generated by
   a. a delay multivibrator.
   b. sweep voltage.
   c. phase shift.
   d. all of the above.
5. A timing wave, tuned to 81.955 kilocycles per second, is generated by
   a. a one-shot multivibrator.
   b. a shock-excited oscillator.
   c. a single-swing blocking oscillator.
   d. none of the above.

True—False

6. The reference mark may take the form of a hairline across the face of the oscilloscope, or a notch or step in the sweep trace.

7. The shock-excited oscillator is very unstable, as the action of the tube depends on the frequency.

8. Oscillations in the cathode circuit of *V1*, figure 8–2, may be sustained by a regenerative circuit.

9. The frequency of oscillation is the resonant frequency of *L1–C2*, figure 8–2, while the amplitude is held constant by the action of the multivibrator.

10. Resistor *R7*, figures 8–3, is a potentiometer which provides a means of controlling the amplitude of the markers.

11. One of the most unstable of oscillators used to generate marker pulses is the negative transconductance oscillator, called the transitron.

12. The output of the transitron oscillator is fed into a cathode follower because this type of circuit provides the low impedance necessary to avoid loading the oscillator.

13. Precise measurement of range requires the accurate measurement of extremely long-time intervals.

14. One commonly used method of producing a variable delay to measure range is to shift the phase of the sine wave.

15. The phase-shifting device is usually geared to a dial, which is calibrated in yards or other suitable units of range.

16. In order to make accurate measurements, one degree of rotation of the phase shifter should produce a change in phase of one electrical degree or less.

17. The reactance of capacitor *C1* or *C2* at the operating frequency of 4.1 kilocycles per second is 4,314 ohms (fig. 8–5).

18. The peaking circuit is a push-pull arrangement whereby two limited-voltage wave forms, one the inverse of the other, are obtained.

19. If only *R6* is varied, figure 8–11, tube *V2* will be made to conduct at intervals corresponding to 2,000 yards of range, because the frequency of the timing voltage was made 81.955 kilocycles per second.

20. The time delay produced by the multivibrator is controlled by varying *C2*.

CHAPTER 9

ANTENNA-POSITIONING SYSTEM

The function of the antenna-positioning system of radar equipments is to position the antenna in azimuth (bearing) and elevation so that its axis takes up the required position.

POINTING ERROR: In describing the operation of the antenna-positioning equipment, we can conveniently use the term "pointing error." By pointing error is meant the difference between the direction in which the antenna is pointing and the required direction. This pointing error can be expressed by the statement that the antenna is off A mils in azimuth and E mils in elevation. The antenna, therefore, must be rotated through A mils in azimuth and E mils in elevation to bring it on the target. The polarity of the two components of the pointing error is important; this polarity specifies whether the antenna must be depressed or elevated and whether it must be rotated clockwise or counterclockwise in azimuth.

In all methods of antenna positioning it is necessary to separate the error signal into two parts or components—the azimuth control signal and the elevation control signal. This is essential because the antenna is brought into the desired position by rotating it the required number of mils in both azimuth and elevation. The two components of the error signal are the voltages which cause the antenna to be rotated so that it takes up the required direction. The reference voltage is the means by which the error signal is separated into its two parts, the azimuth control signal and the elevation control signal.

ERROR SIGNAL AND REFERENCE VOLTAGE

The error signal and the reference voltage can be considered as the input to the antenna-positioning system, the output being the movement of the antenna in azimuth and elevation until its axis takes up the desired direction.

The error signal is a voltage that provides information concerning the direction and magnitude of the pointing error. When tracking a target automatically, the error signal is a measure of the amount by which the axis of the antenna is off the target.

POINTING DATA AND AUTOMATIC TRACKING

REFERENCE VOLTAGE: In order to produce the azimuth and elevation control voltages from the reflected signals shown in figure 9–1, it is necessary to use azimuth and elevation reference voltages supplied by the reference generator. This generator is a 2-phase generator mounted on the antenna shaft and driven by the spinner motor that drives the antenna shaft.

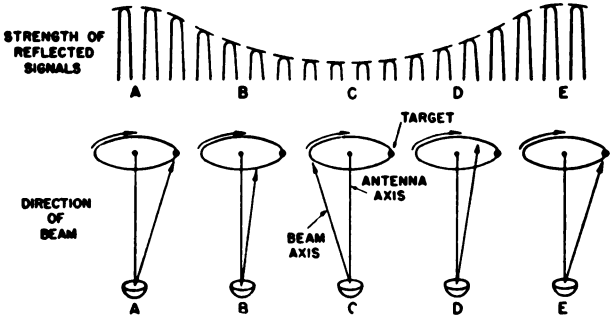
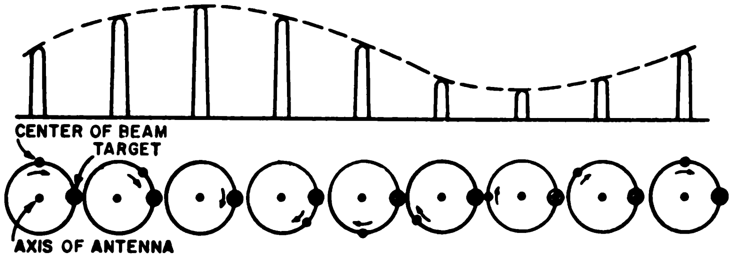


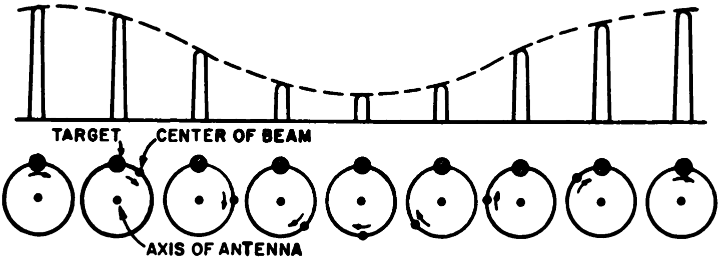
Figure 9–1.—30-cycle variation in echo signals.

The two reference voltages are 90° out of phase with each other because, as shown in the next paragraph, an azimuth pointing error produces a sine-wave error signal that is 90° out of phase with the sine-wave error signal produced by an elevation error. (A "pure" azimuth error is an error in which the target is neither above nor below the axis of the antenna, but is directly to the right or left).

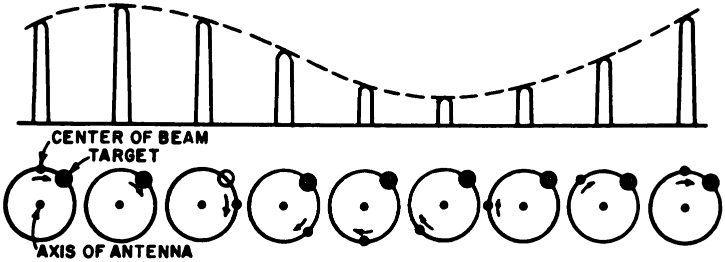
The error signal resulting from a pointing error only in azimuth is shown in figure 9–2A, and the error signal resulting from a pointing error only in elevation is shown in figure 9–2B. In figure 9–2 the antenna axis is viewed head-on, so that the antenna axis is represented as a dot at the center of the circle. The center of the beam is represented also by another dot, which marks the circular path taken by



A. SHOWING PURE AZIMUTH ERROR AND RESULTING SINE WAVE



B. SHOWING PURE ELEVATION ERROR AND RESULTING SINE WAVE



C. SHOWING ERROR IN BOTH AZIMUTH AND ELEVATION, AND RESULTING SINE WAVE

Figure 9–2.—Signals produced by azimuth and elevation pointing errors.

the beam as it spins about the antenna axis. The target is represented by a small crosshatched circle. The amplitude of the echo signal for various positions of the beam is shown directly above the corresponding circular diagram that shows the beam position. Figure 9–2A and 9–2B show that the error signal produced by a pure azimuth error lags the error signal produced by a pure elevation error by 90°.

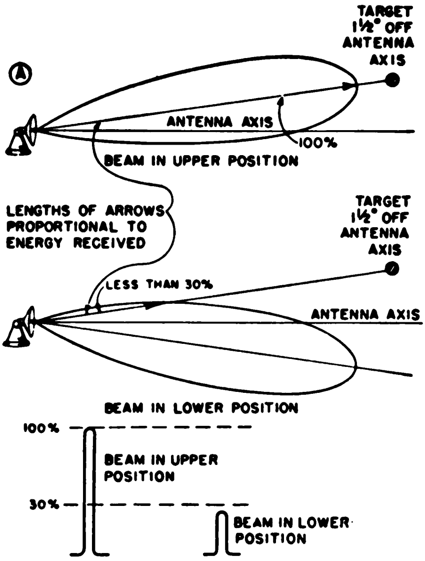
POINTING ERROR IN BOTH AZIMUTH AND ELEVATION. The error signal produced when there is a pointing error in both azimuth and elevation is shown in figure 9–2C. As to be expected, the error signal in figure 9–2C reaches its maximum at a point that is between the points at which the error signals in figures 9–2A and 9–2B reach their maximum values. The reference voltages are not shown in figure 9–2. However, the azimuth reference voltage is in phase with the error signal which is produced by a pure azimuth pointing error (fig. 9–2A), whereas the elevation reference voltage is in phase with the elevation error signal that is produced by a pure elevation pointing error (fig. 9–2B).

ZERO POINTING ERROR (ON TARGET)

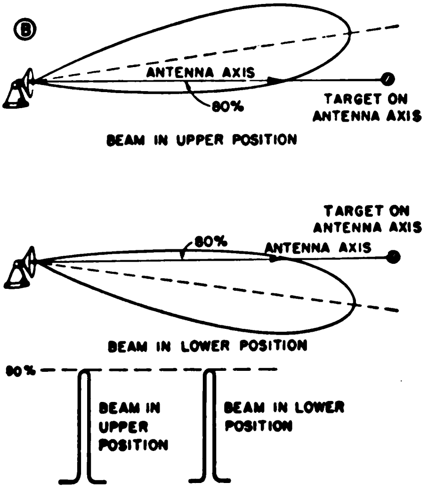
When the axis of the antenna points directly at the target, the echo signals have the same amplitude for every position of the beam as it rotates about the antenna axis. This is seen from an inspection of figure 9–3, which shows the beam striking the target for the two special cases: when the beam axis is below the target, and when the beam axis is above the target. The same situation applies for every other position of the beam, and the reflected echoes are 80 percent of the maximum strength.

BLOCK DIAGRAM OF ANTENNA-POSITIONING SYSTEM

A block diagram of the antenna-positioning system is shown in figure 9–4. This diagram illustrates the way in which the antenna-positioning system responds to the error voltage and reference voltage. Both the azimuth and ele-



RETURN SIGNALS FROM TARGET
1½° OFF ANTENNA AXIS



RETURN SIGNALS FROM TARGET
ON ANTENNA AXIS

Figure 9–3.—Echo signals with conical scan.

vation channels are shown in this figure. Since the operation of the two channels is the same, the explanation is confined to the azimuth channel only.

The first block in this diagram is the commutator circuit which has as its inputs the error signal and the azimuth reference voltage. This circuit takes these two inputs and produces from then an output voltage which is called azimuth control voltage. This is a d-c voltage that varies in the following ways:

1. When the azimuth pointing error is zero, the azimuth control voltage produced in the output of the commutator circuit is also zero.

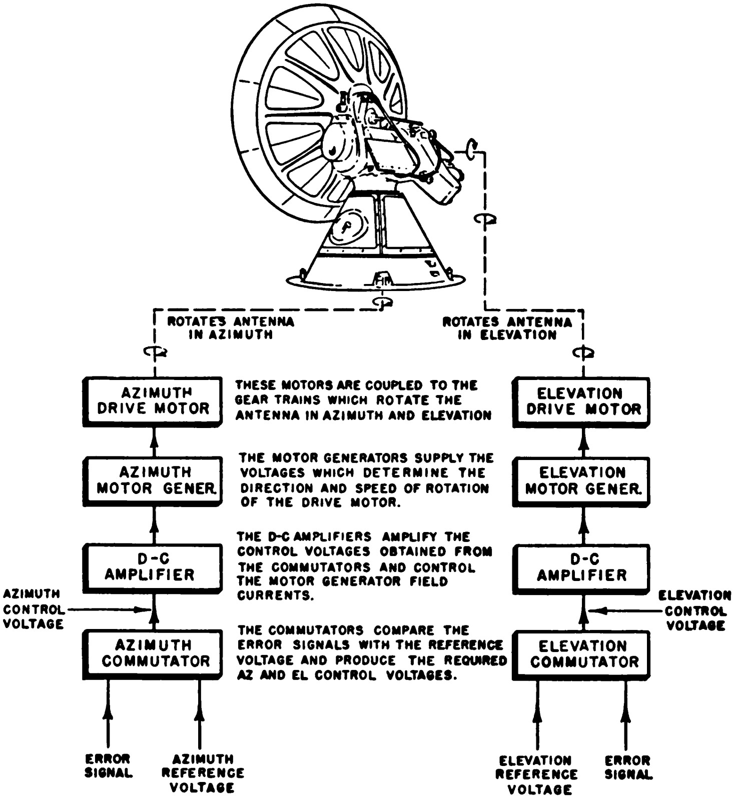

ROTATES ANTENNA IN AZIMUTH
ROTATES ANTENNA IN ELEVATION
AZIMUTH DRIVE MOTOR
THESE MOTORS ARE COUPLED TO THE GEAR TRAINS WHICH ROTATE THE ANTENNA IN AZIMUTH AND ELEVATION
ELEVATION DRIVE MOTOR
AZIMUTH MOTOR GENER.
THE MOTOR GENERATORS SUPPLY THE VOLTAGES WHICH DETERMINE THE DIRECTION AND SPEED OF ROTATION OF THE DRIVE MOTOR.
ELEVATION MOTOR GENER.
D-C AMPLIFIER
THE D-C AMPLIFIERS AMPLIFY THE CONTROL VOLTAGES OBTAINED FROM THE COMMUTATORS AND CONTROL THE MOTOR GENERATOR FIELD CURRENTS.
D-C AMPLIFIER
AZIMUTH CONTROL VOLTAGE
ELEVATION CONTROL VOLTAGE
AZIMUTH COMMUTATOR
THE COMMUTATORS COMPARE THE ERROR SIGNALS WITH THE REFERENCE VOLTAGE AND PRODUCE THE REQUIRED AZ AND EL CONTROL VOLTAGES.
ELEVATION COMMUTATOR
ERROR SIGNAL
AZIMUTH REFERENCE VOLTAGE
ELEVATION REFERENCE VOLTAGE
ERROR SIGNAL

Figure 9–4.—Block diagram of antenna-positioning system.

2. When the azimuth pointing error is such that the antenna must be rotated clockwise, the azimuth control voltage is a positive d-c voltage. The greater the azimuth pointing error, the greater is this d-c control voltage.

3. When the azimuth pointing error is such that the antenna must be rotated counterclockwise, the azimuth control voltage is a negative d-c voltage. The greater the azimuth error, the greater is this d-c control voltage.

D-C AMPLIFIER

The d-c control voltage produced by the commutator circuit is fed to a d-c amplifier (in the azimuth and elevation tracking unit), which amplifies the d-c control voltage. This amplification is required because the azimuth control voltage must produce a d-c current for the generator field of the azimuth motor generator. This d-c current is made to vary in the same way that the azimuth control voltage varies, as described in the preceding paragraph.

MOTOR GENERATOR

The azimuth motor generator is a generator driven at a constant speed by a motor. Both the motor and the generator armatures are on the same shaft. The motor field and the generator field are, however, entirely separate. The output of the generator depends on the current supplied to the generator field. When the generator-field current is zero, the output of the generator is zero. When the generator-field current is positive, the output is positive. The greater the field current is, the greater is the output. Similarly, when the d-c control voltage is negative, the generator-field current is negative, and the output of the motor generator is negative.

DRIVE MOTOR

The output of the azimuth motor generator is fed to the azimuth drive motor. This drive motor is geared to the shaft, which rotates the antenna in azimuth. When the azimuth control voltage is zero, the output of the motor generator is zero and the drive motor is stationary. When the azimuth control voltage is positive, the positive output of the motor generator causes the drive motor to turn the antenna, so that it approaches the required azimuth direction. When the azimuth control voltage is negative, the resulting negative output of the motor generator again causes the drive motor to turn the antenna so as to point it in the required azimuth direction.

SERVO LOOP

An important idea associated with the system shown in figure 9–4 is the complete loop or circle of action, which is a "servo loop" or "servo mechanism." The following chain of events takes place when the antenna is positioned by means of an error voltage:

1. To begin with, the antenna is pointing in the wrong direction and there is a given amount of azimuth error. Information regarding this error is carried to the input of the antenna-positioning system by the error signal.
2. The antenna-positioning system takes this error signal and produces from it an azimuth control voltage which causes the drive motors to move the antenna in such a direction as to reduce the azimuth error.
3. The instant that the azimuth pointing error is reduced in this way, the effect of the reduction in the pointing error is to reduce the error signal.
4. The drive motor continues moving the antenna so as to reduce the pointing error, while the error signal continues to decrease until the azimuth pointing error is zero, at which time the error signal is zero.
5. This type of system is called a servo mechanism because the error signal that causes the movement of the antenna is itself affected by the movement that it produces. Note that a very small amount of power, in the form of the error signal, controls the movement of the antenna, even though this requires an enormously greater power than is contained in the error signal.

ERROR SIGNAL—AUTOMATIC TRACKING

In automatic tracking the error signal is produced as the result of spinning the antenna. The antenna system is designed to produce a beam which is offset from the axis of the reflector so that the spinning of the antenna results in conical scanning. In this way the beam explores the space in the vicinity of the target and produces an error signal that reveals the direction of the target with respect to the direction in which the axis of the antenna is pointing.

REFERENCE VOLTAGE—AUTOMATIC TRACKING

In automatic tracking the reference voltage is produced by a reference generator coupled to the antenna shaft. This generator contains two coils at right angles to each other. The voltage induced in one of these coils by the spinning armature of the reference generator is the azimuth voltage, whereas the voltage induced in the other field coil is the elevation reference voltage.

The azimuth commutator (fig. 9–4) takes the error signal and the azimuth reference voltage and combines them in a special circuit to produce the azimuth control voltage. This control voltage is amplified and applied to the azimuth drive motor in order to correct the azimuth position of the antenna.

AUTOMATIC TRACKING UNIT

The output of the receiver unit is fed to the automatic tracking unit (fig. 9–5). The input to the automatic tracking unit is thus a series of video pips, the amplitude of which varies, as the antenna spins and explores the space around the target, in such a way as to reveal the position of the target.

The purpose of the first stage of the automatic tracking unit—the error signal detector—is to detect the video echoes or pips and produce the signal. This indicates the manner in which the video signals are varying. This is the 30-cycle voltage which forms the error signal. The error signal is amplified in the error signal amplifier and then passed on to a balanced amplifier, the output of which is the output of the

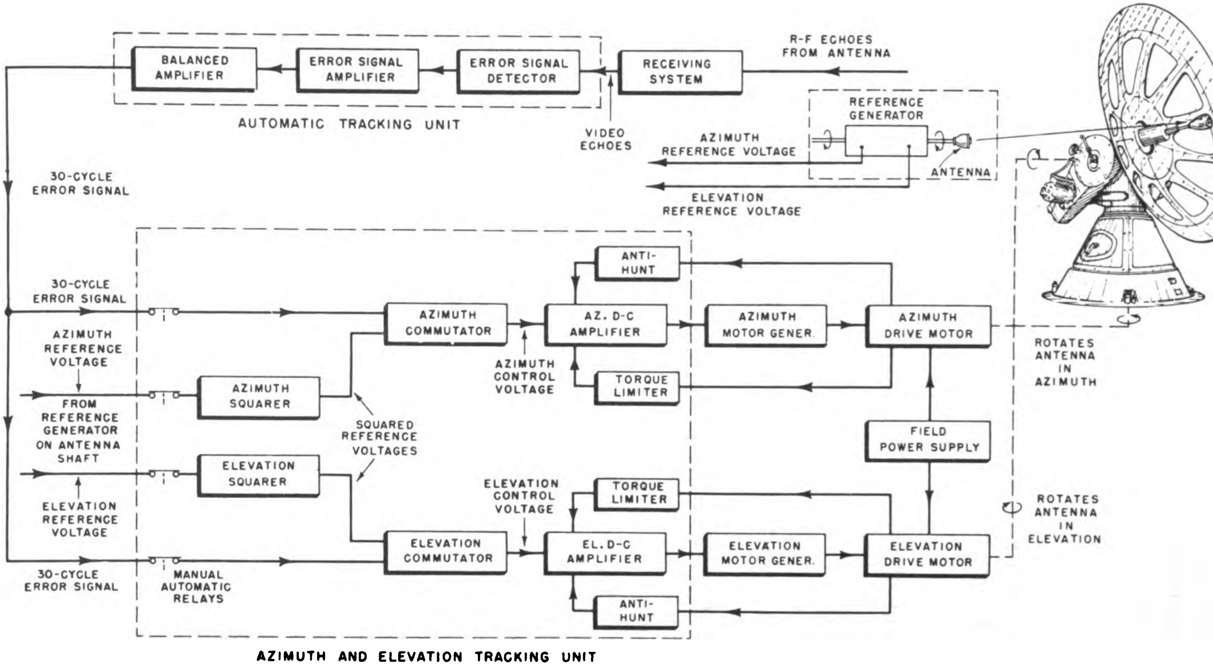


Figure 9–5.—Block diagram of automatic tracking system.

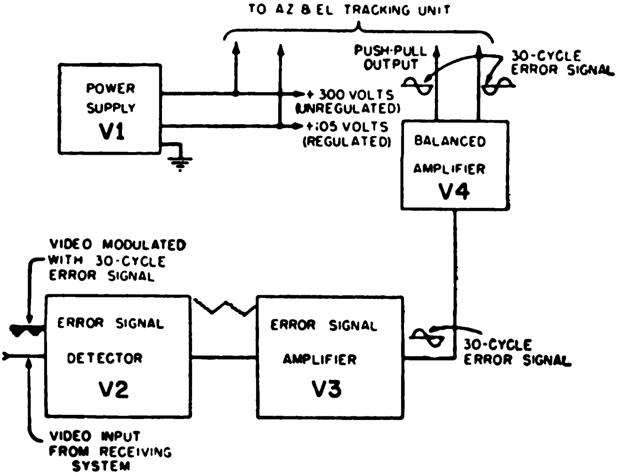


Figure 9–6.—Block diagram of automatic tracking unit.

automatic tracking unit. It should be emphasized that, when on target, this 30-cycle error output of the automatic tracking unit is zero. When off target, the 30-cycle error signal varies in amplitude and phase in such a way as to indicate the position of the target with reference to the direction in which the antenna is pointing.

The general functioning of the automatic tracking unit is shown by the block diagram in figure 9–6. The video signals are fed into a detector stage called the error-signal detector, since it detects the 30-cycle error signal from the video pulses. The error-signal amplifier completes the detection and produces a smooth sine wave proportional to the error signal. The balanced amplifier amplifies the error signal and feeds a push-pull output, which controls the azimuth and elevation tracking units. The power supply section is a single full-wave rectifier, with a regulator tube across a portion of the output to provide 105 volts (regulated) in addition to the main 300-volt output.

DETECTION CIRCUIT

The primary function of the automatic tracking unit is to detect the video echoes so as to produce the 30-cycle error signal (see fig. 9–7). The detection is accomplished by tubes *V2* and *V3*, and the *RC* circuit formed by resistor *R4* and capacitor *C2*. *V2* functions as the error-signal detector, and *V3* functions as the error-signal amplifier. The negative video pulses, modulated at 30 cycles, are applied to the cathode of *V2* across resistor *R2* and through resistor *R1* (fig. 9–8).

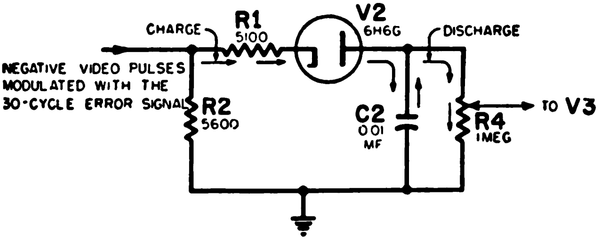
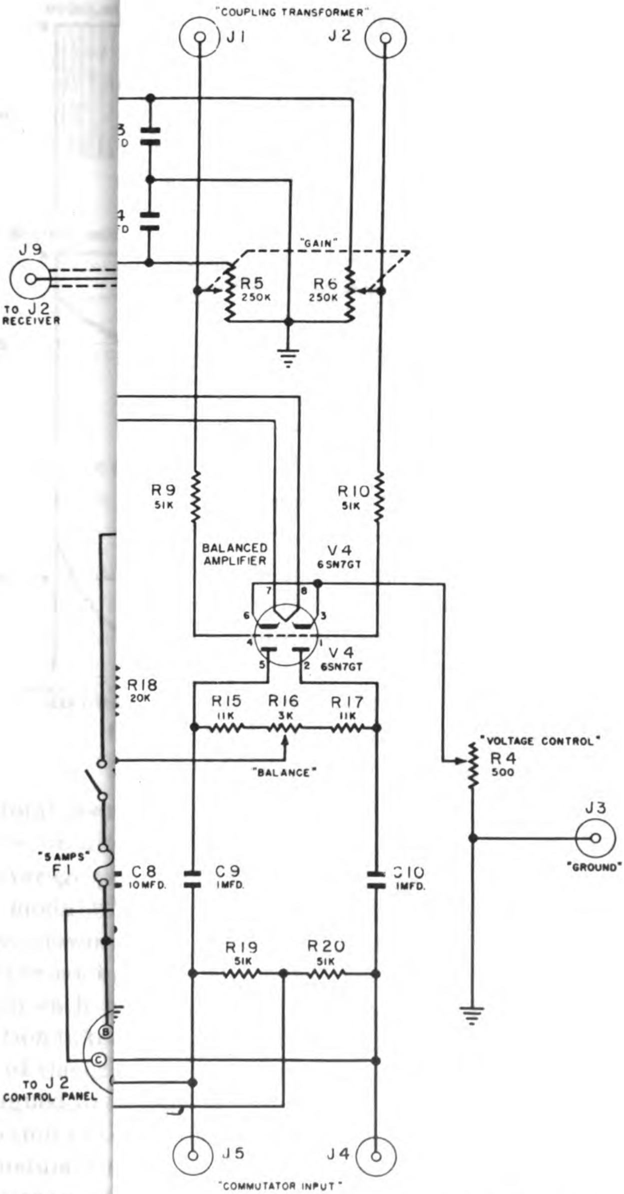


Figure 9–8.—Simplified diagram of error-signal detector.

The voltage at the plate of the detector tends to follow the peak height of the video signals, since capacitor *C2* charges at a fast rate through the tube during the pulse. But it discharges at a slow rate between pulses through resistor *R4* which is 1 megohm. This is shown in the wave of output of the *RC* circuit in figure 9–9B. Note that the slope of the charge curve is much steeper than that of the discharge curve.

ERROR-SIGNAL AMPLIFIER

Figure 9–9 shows the input to *V2*, the output of the detection circuit, and the output of transformer *T1*, which is described below. *V3* is an amplifier with an automatic-volume-control action. The output of the detection circuit is fed to the control grid of *V3* (fig. 9–7) at a negative d-c level that averages about 6 volts. The characteristics of *V3* are such that an increase in the value of the bias, which would be brought about by the reception of stronger signals, results in a decrease in the a-c gain of the amplifier, as shown in figure 9–10. The reception of weaker signals results in a decrease in the bias and an increase in the gain of the amplifier.


"COUPLING TRANSFORMER"
J1
J2
3
D
4
D
"GAIN"
J9
TO J2
RECEIVER
R5
250K
R6
250K
R9
51K
R10
51K
BALANCED
AMPLIFIER
V4
6SN7GT
7
8
6
3
4
1
5
2
V4
6SN7GT
R18
20K
R15
11K
R16
3K
R17
11K
"BALANCE"
"VOLTAGE CONTROL"
R4
500
J3
"GROUND"
"5 AMPS"
F1
C8
10 MFD.
C9
1MFD.
C10
1MFD.
R19
51K
R20
51K
B
C
TO J 2
CONTROL PANEL
J5
J4
"COMMUTATOR INPUT"

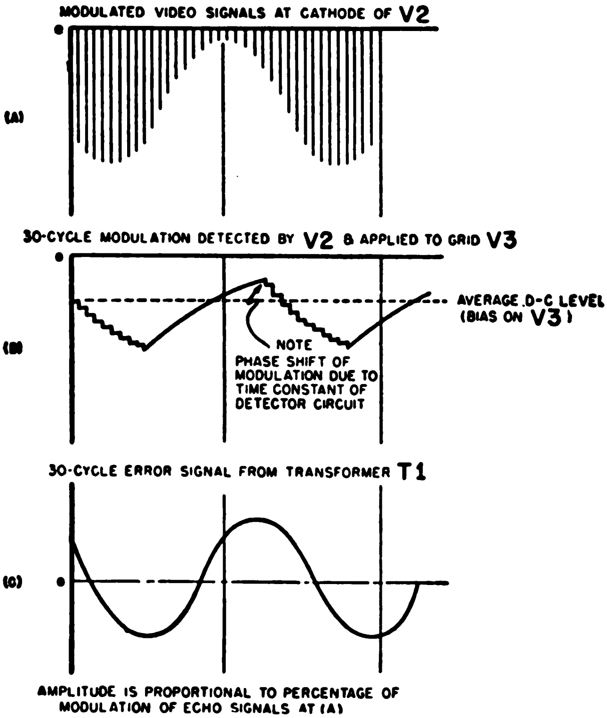

MODULATED VIDEO SIGNALS AT CATHODE OF V2
(A)
30-CYCLE MODULATION DETECTED BY V2 & APPLIED TO GRID V3
(B)
AVERAGE D-C LEVEL (BIAS ON V3)
NOTE
PHASE SHIFT OF MODULATION DUE TO TIME CONSTANT OF DETECTOR CIRCUIT
30-CYCLE ERROR SIGNAL FROM TRANSFORMER T1
(C)
AMPLITUDE IS PROPORTIONAL TO PERCENTAGE OF MODULATION OF ECHO SIGNALS AT (A)

Figure 9–9.—Error-signal wave forms.

The total result is that the magnitude of the error signal in the plate circuit of the amplifier is practically independent of the average pulse height, and depends only on the percentage of modulation present in the modulated video signals. Thus, as shown in figure 9–10, the output would be approximately the same if the input varied from 4 to 6, 8 to 12, or 16 to 24; in each the percentage of modulation is 20 percent. This action takes care of rapid fluctuations in the average intensity of the echo signals, which the AGC of the receiver is not designed to follow. In this connection note that perfect AGC action in the receiver would eliminate even the 30-cycle error modulation.

In order to adjust the operating point so that the required portion of the tube characteristic is used, the automatic vol-

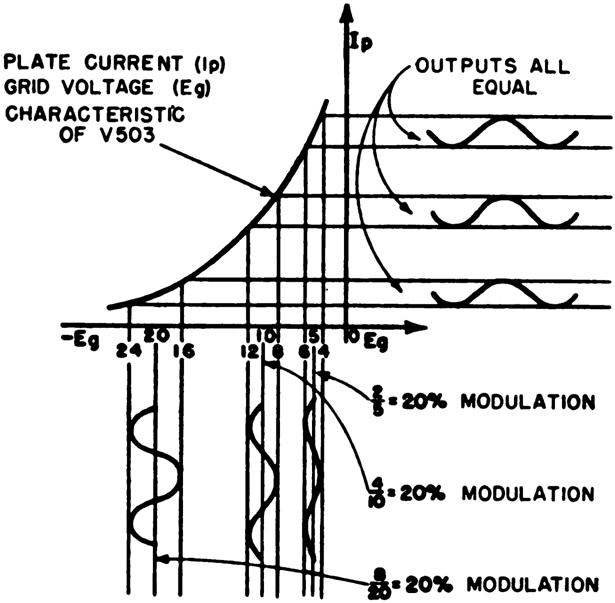


Figure 9–10.—Automatic control action of error-signal amplifier.

ume control on the panel should be set so that meter *M1* reads 6 milliamperes with the antenna directed at a fixed target, and the control switch set on AUTOMATIC.

The plate current of *V3*, which is similar to the 30-cycle wave obtained from the *R–C* circuit, flows through the primary of inverter transformer *T1* (fig. 9–7). The secondary of this transformer is tuned to approximately 30 cycles by capacitors *C3* and *C4*. Because of this tuning, the secondary of the transformer puts out a practically smooth 30-cycle sine wave, even though a distorted 30-cycle wave flows in the primary. The secondary is center-tapped to provide an input for the push-pull circuit of the balanced amplifier, which is the next stage.

BALANCED AMPLIFIER

As shown in figure 9–7, the output of transformer *T1* is applied to the grids of balanced amplifier *V4* by potentiometers *R5* and *R6*, which act as voltage dividers to allow adjustment of the amount of input to *V4*. Both potentiometers are adjusted by the "GAIN" control on the panel of the unit. Resistors *R9* and *R10* limit the amount of current that can be drawn by the grids of *V4*. The cathodes of the balanced amplifier are connected. Cathode bias is obtained through the voltage control resistor *R14*, which should be set to obtain 2.9 volts.

Plate voltage for the two halves of *V4* is supplied through the balanced potentiometer *R16*. The control compensates for any unbalance in the two halves of the double triode. When it is properly set, the meters of the azimuth and elevation tracking units are balanced, with no signal in the narrow gate and with the control switch set for AUTOMATIC. The push-pull signal output of the balanced amplifier is fed into the azimuth and elevation tracking units. This push-pull sine-wave serves as the error signal when the equipment is operating on AUTOMATIC.

PHASE SHIFTS IN AUTOMATIC TRACKING UNIT

Figure 9–9 shows that the peaks of the three waves represented do not fall one underneath another, because of phase shifts that occur between stages. This results in no trouble as long as the phase shifts remain constant, since the phase of the reference voltages may be set with respect to the push-pull error signal regardless of how much this error signal may lag the modulation on the echo signals.

This setting of the reference voltages is accomplished by shifting the fields of the reference generator. It is important to remember, however, that any change in the phase shifts shown in figure 9–9 destroys the synchronism between the error voltages and the reference voltages, and results in poor tracking.

AZIMUTH AND ELEVATION TRACKING UNIT

The 30-cycle error signal output of the automatic tracking unit is fed to the input of the azimuth and elevation tracking unit. As shown in figure 9–5, the azimuth and elevation tracking unit is divided into two similar channels—the azimuth channel and elevation channel. In the following description only the azimuth channel is described, but it should be understood that everything said about the azimuth channel applies equally well to the elevation channel.

The tracking units accept the error signals and reference voltages and deliver a current to the motor generator. This current is proportional to the pointing error. Each channel contains a squarer tube, two commutator tubes, two d-c amplifiers, an antihunt amplifier and limiter, and a torque-limiter tube. The functions of the stages in block diagram of figure 9–4 are described below:

1. The squarer tube receives the reference voltage and develops a rectangular output, which is fed to the plates of the commutator tubes.
2. The commutator tubes receive the error signal and develop a d-c push-pull output. The polarity and magnitude of this d-c output depend on the strength of the error signal and its phase with respect to the reference voltage.
3. The d-c amplifier develops a comparatively large current from the output of the commutator tubes, and it feeds this current to the field of the motor generator, thus generating a voltage to turn the antenna drive motors.
4. The antihunt tubes receive voltages from the drive motors. These voltages are used to provide feedback. This feedback makes the actions of the antenna in coming to a new position smoother and more positive. The inertia of the heavy antenna mount and the lag in the control circuits are capable of causing oscillations or hunting of the antenna in finding its correct position. This feedback is designed to overcome the effects of hunting and make the positioning of the antenna smooth, fast, and positive. The antihunt limiters prevent the antihunt action from becoming too strong by limiting the antihunt feedback voltage.
5. The torque-limiting tubes act on the d-c amplifiers and prevent them from ever sending too large a current into the motor generator. Excessively large currents would damage the driving mechanism and overheat the electrical circuits.

COMMUTATOR STAGE

The error-signal output of the automatic tracking unit and the reference voltage from the reference generator are fed to the commutator state where they are combined, and this output is the control voltage.

The plates of the squarer tubes are directly connected to the plates of the commutator tubes (fig. 9–11). As a result of this connection, with no error-signal input, one-half of each commutator conducts and the other half is completely cut off at every instant.

The characteristics of the 6SN7GT are such that a plate voltage of 150 and a grid voltage of 75 result in a cathode

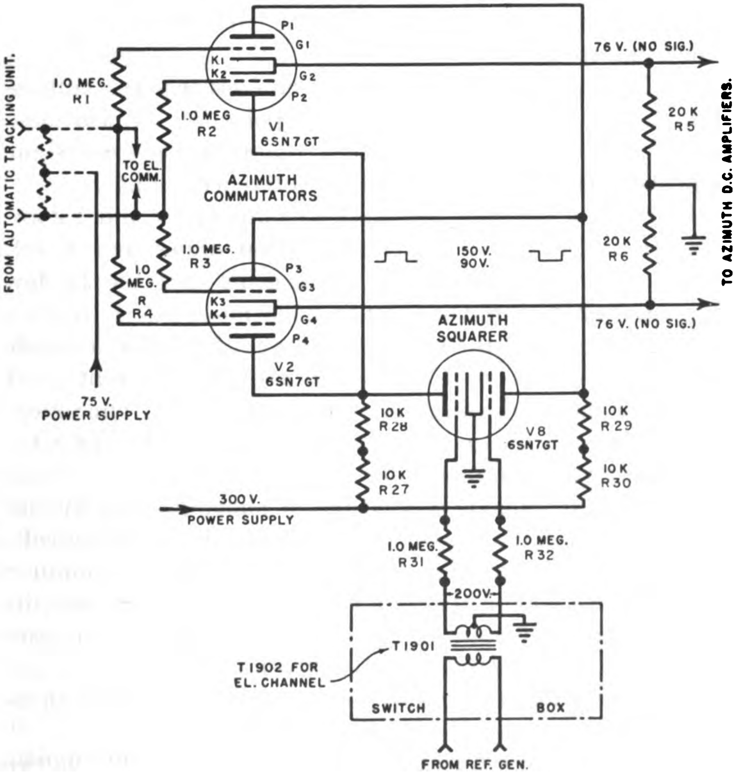


Figure 9–11.—Simplified schematic diagram of commutator and squarer circuit.

voltage of 76 across the 20,000 ohm cathode resistor. With 90 volts on the plate, 75 volts on the grid, and 76 volts on the cathode, the tube is cut off. Since the two cathodes of the commutator tube are connected, the application of 150 volts to one plate and 90 volts to the other results in a cutoff condition for the latter half of the tube. The same is true of the other commutator tube. Thus, since either one leg or the other of both tubes conducts at every instant, there is a steady flow of current through resistor *R5* from *V1*, and through *R6* from *V2*. As a result, the voltages of both cathodes, which are applied to the grids of the d-c amplifier in the next state, are constant.

ERROR SIGNAL IN PHASE WITH REFERENCE VOLTAGE

Refer to figures 9–11 and 9–12A in following this discussion. Let the applied error signal be such that the voltage on grid *G1* is in phase with the voltage on *P1*. When these two voltages are in phase, *G2* is in phase with *P2*, *G3* is out of phase with *P3*, and *G4* is out of phase with *P4*.

With *P1* at 150 volts, the upper halves of *V1* and *V2* are in a conducting condition, and the lower halves are cut off. Therefore, only the voltages on *G1* and *G3* influence the flow of current in the commutator tubes. Since *G1* is in its positive half cycle and *G3* is in its negative half cycle, there is an increase of current in *R5* with respect to the condition of no error signal and a decrease of current in *R6*. The potential on cathodes *K1* and *K2* rises, and the potential of cathodes *K3* and *K4* falls.

On the next half cycle, *P1* and *P3* are at 90 volts so that the upper halves of the tubes are cut off, and only the voltages on *G2* and *G4* influence the current in the commutator tubes. *G2* is now in its positive half cycle and *G4* is in its negative half cycle, so that again there has been an increase of current through *R5* over the no-error-signal condition and a decrease through *R6*. The cathodes follow the same curve they followed in the first half cycle.

Because of the difference in the currents through the two resistors, the average potential of the cathode of *V1* is higher

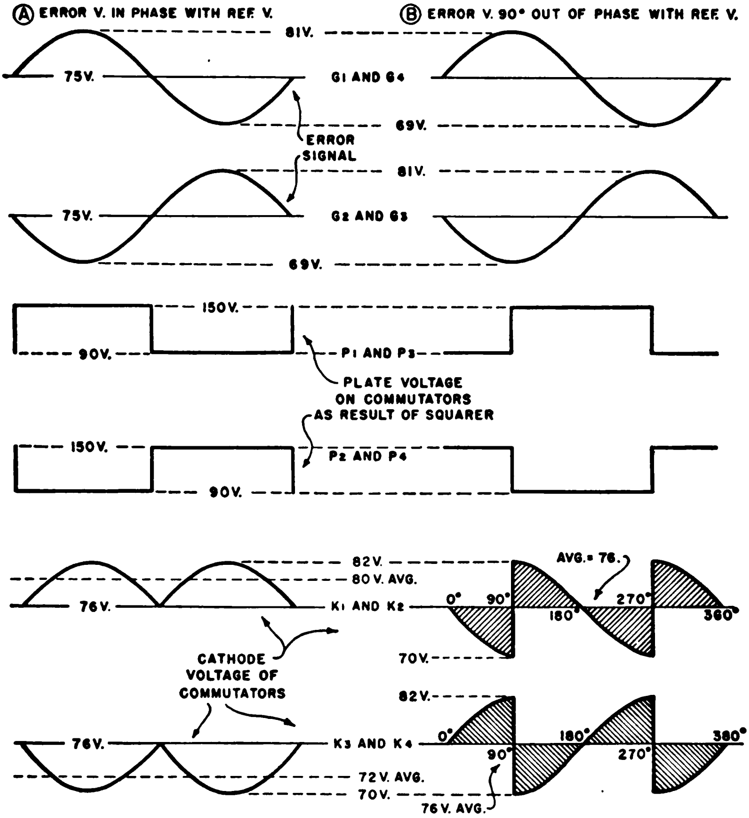


Figure 9–12.—Wave forms of commutator and squarer circuit.

than the average potential of the cathode of *V2*. The current changes take place at 30 cycles, and the filter circuit that follows feeds to the grids of the d-c amplifier tubes *V3* and *V4* the d-c voltages equal to the average value of the varying voltages on the cathodes of the commutator tubes.

ERROR SIGNAL 90° OUT OF PHASE WITH REFERENCE VOLTAGE

Referring to figure 9–12B, at the start of the cycle the upper halves of the commutator tubes are cut off and the lower halves are conducting. Therefore, *G2* and *G4* control the outputs of the tubes. Between 0° and 90° of the error signal, the voltage of *G2* falls to its minimum and the voltage of *G4* rises to its maximum, causing the cathode voltage of *V1* to fall, and the cathode voltage of *V2* to rise.

At 90° the upper halves of the tubes suddenly become conductive, while the lower halves are suddenly cut off. As a result, *G1* and *G3* become the driving elements. Since the voltage on *G1* is at its maximum and that on *G3* at its minimum, the voltage at the cathode of *V1* rises to a maximum and the voltage on the cathode of *V2* falls to its minimum. Between 90° and 270° *G1* and *G3* continue as the driving elements and the cathode voltages follow them, the cathode voltage of *V1* ending on a minimum, and that of *V2* on a maximum.

At 270° the upper halves of the tubes again are cut off, the lower halves become conductive, and *G2* and *G4* again become the driving grids. Since *G2* is at its high value and *G4* at its low value, the cathode voltage of *V1* jumps again to a maximum and that of *V2* drops again to a minimum. From this point to the end of the cycle the cathode of *V1* follows *G2* and that of *V2* follows *G4*.

Figure 9–12B shows that the average value of both cathode voltages is the same as the value obtained with no error voltage on the grids, since the curve is above and below the d-c level for equal intervals. Thus, zero control voltages are produced when the error signal is 90° out of phase with the reference voltage. Note that if the voltages on the plates of the commutator tubes had come from the azimuth reference voltage, the error signal just considered would have been produced by a pure elevation error.

SQUARER STAGE

The azimuth reference voltage is applied to the input of the azimuth commutator through an azimuth squarer stage (fig. 9–5). The squarer helps the commutator to produce the azimuth control voltage. Each grid of the squarer tube (fig. 9–11) is fed with a 115-volt sine wave. The cathodes are at ground potential, and the effect of this large voltage on the grids of the tube is to drive the tubes very quickly to cutoff on the negative half cycle, and to saturation on the positive half cycle, producing a square wave of output voltage. At cutoff the plates are at 150 volts, and at saturation they are at 90 volts. When on AUTOMATIC, the azimuth squarer is fed with a 200-volt 30-cycle wave from *T1901*. This transformer is fed the reference voltage from the reference generator in the pedestal. The elevation squarer is fed the elevation reference voltage through *T1902*.

D-C AMPLIFIER, MOTOR GENERATOR, AND DRIVE MOTOR

The azimuth control voltage is fed to the next stage in the tracking unit, which is the d-c amplifier, where the control voltage is amplified to a level sufficiently high to control the voltage output of the azimuth motor generator. The output of the generator is applied to the drive motor and controls its direction and speed of rotation in such a way as to bring the antenna on target.

With the antenna on target, the error signal is reduced to zero so that the antenna remains on target. Should the target change its position, the error signal increases from zero; as soon as this happens, an azimuth control voltage is created which quickly brings the antenna back on the target. All this action takes place so smoothly and so continuously that the antenna never gets off target more than a few mils.

The average voltages of the commutator cathodes are impressed upon the control grids of the d-c amplifier *V3* and *V4*, through filter circuits (*L1*, *R20*, and *C1*, *L2*, *R21* and *C2*), and through the grid resistor *R7* and *R9* (fig. 9–13). The purpose of the d-c amplifiers is to control the field of the motor generators.

Each generator has two control fields connected so that the magnetic flux produced by the two windings is opposing; hence, only an unbalance in the two fields will produce an output of the motor generator. The current of the d-c amplifiers is the current in the fields since the fields are the plate load for the amplifiers.

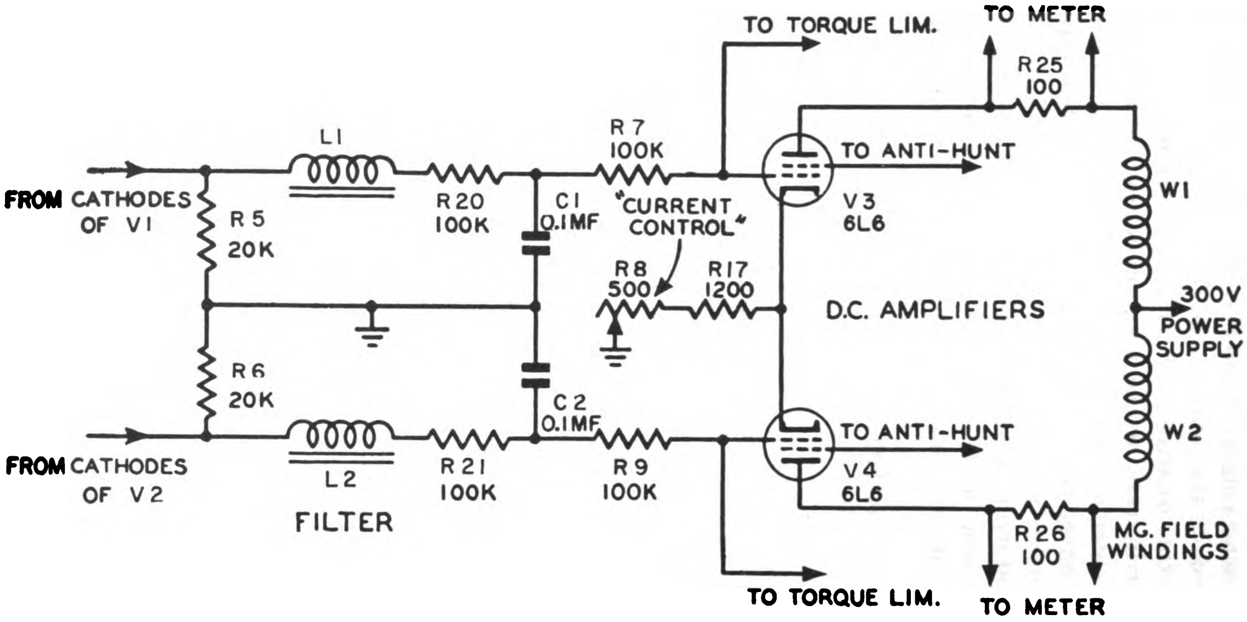


Figure 9-13.—Simplified diagram of d-c amplifier.

As shown in figure 9–13, the field current meters of the tracking units are connected so that they may read the two field currents of either the azimuth or the elevation motor generator by reading the IR drop across *R25* and *R26*, or across *R75* and *R76*. *R8* and *R58* are the current-control potentiometers and adjust the current to the normal value of 25 ma.

With no error signal and no unbalance in the output of the commutators, the currents of the d-c amplifiers are equal, and the antenna will not move as the motor-generator fields will balance. If there is an error signal, the output of the commutators is unbalanced and is applied directly to the grids of the d-c amplifiers, which unbalances the fields. Hence a net field exists in the motor generator to produce an output.

TORQUE-LIMITING CIRCUIT

To prevent violent slewing of the antenna and overloading of the drive motors, a circuit was designed to limit the output of the motor generator. A voltage taken from the drive-motor circuit is fed back to the d-c amplifier in such a way as to limit the torque which can be applied by the drive motors to the antenna.

The torque-limiting circuit (fig. 9–14) reduces the control grid voltage of that d-c amplifier which is sending excessive current into the motor-generator field winding. This circuit does not begin to operate until the current has reached a certain value, and plays an important part in manual and remote operation. If the control synchros are turned fast to position the antenna, large voltages are impressed on the amplifier grids in such a direction as to limit the torque to a safe value.

V7 is the torque-limiting tube. The cathode voltage is obtained from the 300-volt supply through a voltage divider and is approximately 33.5 volts. The grid voltages are supplied from the ends of the commutator field winding of the drive motor in the pedestal. The center tap of this winding is held at a potential of 30 volts, which is obtained from the voltage divider that supplies the cathode voltage. With no current

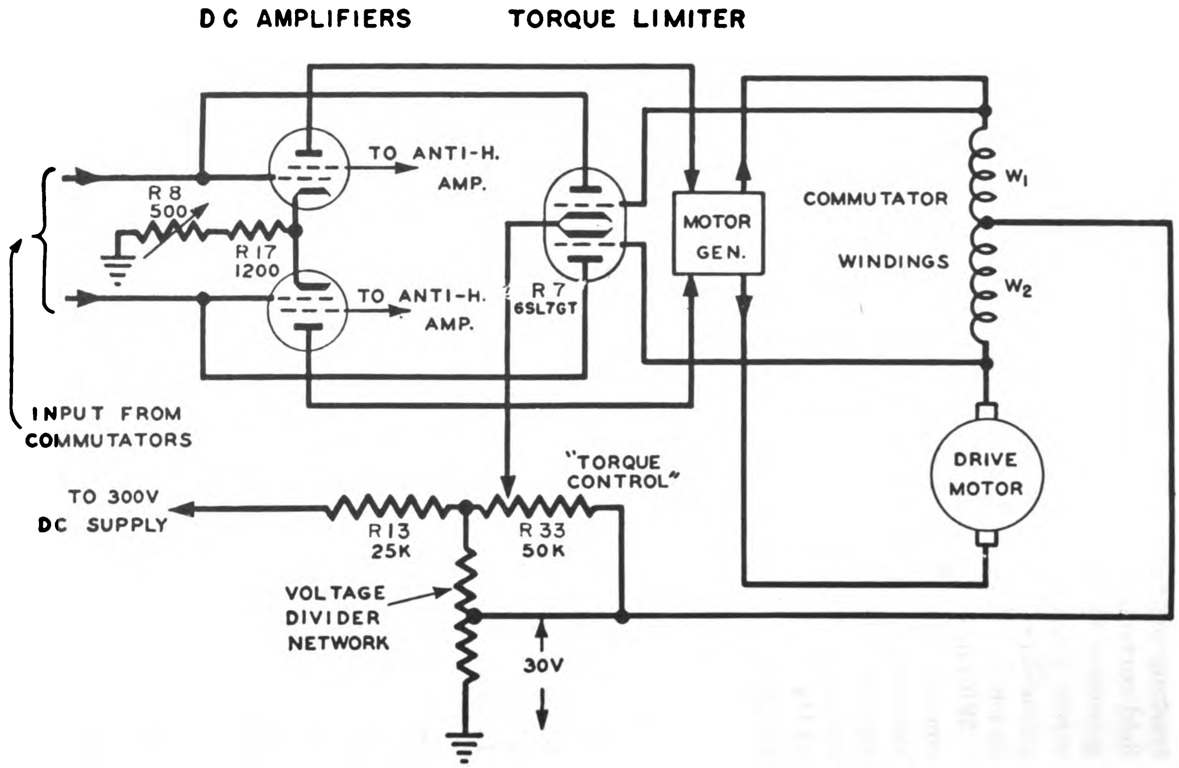


Figure 9–14.—Simplified schematic diagram of the torque-limiting circuit.

in the armature of the drive motor, the grids are also at 30 volts. Since the plates of the torque limiter are connected to the control grids of the d-c amplifiers, their potentials are approximately 76 volts, and under static conditions these voltage values put the torque limiter well below cutoff.

If a large signal is applied to the grids of the d-c amplifier, the motor generator supplies a large current to the armature of the drive motor in such a direction as to make the end of winding W*1* positive with respect to the 30-volt potential of the center tap and thus raises the voltage applied to the upper grid of the torque limiter. When this grid bias reaches a certain potential, the upper half of the tube conducts and drops the grid voltage of the d-c amplifier. This reduces the plate current of the d-c amplifier and the torque applied to the drive motor. For a current in the opposite direction through the windings, the other half of *V7* conducts.

ANTIHUNT CIRCUIT

In positioning the antenna, the drive motor turns the antenna to the position chosen by the operator or to the position of zero error signal. But when this position is reached, the motor can not stop suddenly on account of the inertia of the system, and so swings past the zero point. On the other side of the zero point the error signal reverses and makes the antenna swing back again. Although it might appear that this oscillation or hunting would die out quickly, this is not always true. The characteristics of the antenna-positioning system are such that often this oscillation increases rather than decreases, and violent hunting takes place. The antihunt circuit prevents this oscillation by means of a feedback voltage, taken from the azimuth drive motor and fed back to the d-c amplifier.

As the motor hunts, the current through its armature varies with the frequency at which the hunting takes place. The antihunt circuit sets up a varying voltage (from this varying current) to damp out the oscillation of the motor. This is called a negative feedback voltage, and is fed to the screen grid of one of the d-c amplifiers (*V3* and *V4*).

The antihunt circuit consists of a resistance divider across one of the commutator windings of the motor, a filter across the output of the resistance divider, another divider across the output of the filter, and the antihunt tube. The plates of the antihunt tube and the screen grids of the d-c amplifier are fed through the same dropping resistor so that an increase in current in the antihunt tube results in a lowering of voltage on the screen grid.

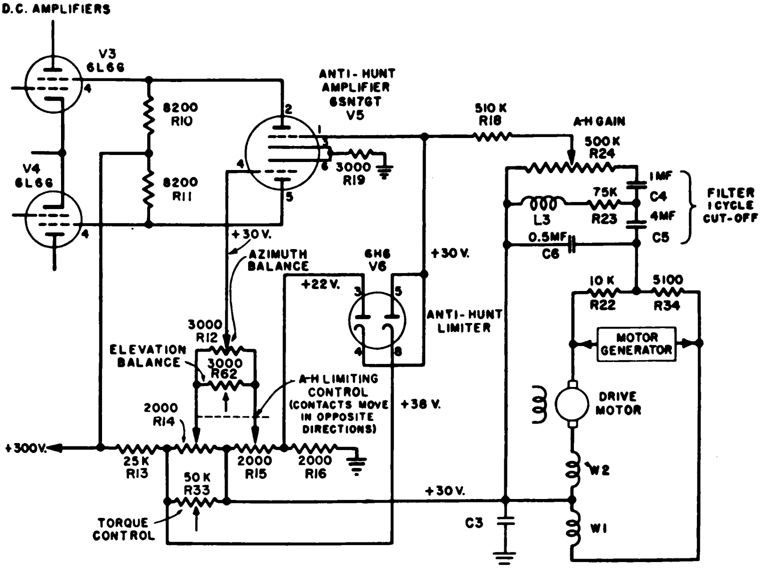


Figure 9–15.—Simplified schematic diagram of the antihunt circuit.

A simplified diagram of the antihunt circuit is shown in figure 9–15. If an oscillating current flows in the armature of the drive motor, a varying voltage exists across the input to the filter. The filter cuts off variations which occur at less than one per second; this restricts the damping effect of the filter to oscillatory motion so that it does not offer negative feedback to rapid movement of the antenna in one direction.

The left end of resistor *R24* (fig. 9–15) is maintained at a steady potential by the voltage divider, which consists of a network of resistors. A voltage coming through the filter generates a varying voltage in potentiometer *R24* that is added to the fixed voltage. The peak magnitude of this voltage applied to the antihunt tube *V5* increases as the contact of the potentiometer is moved to the right. The voltage output of *R24* is applied to the upper grid of the antihunt tube *V5*. As a result, a voltage is applied to the screen grid of *V3* since the plate of *V5* and the screen grid of *V3* are fed through the same dropping resistor.

In figure 9–15 you will note that one plate of antihunt tube *V5* is connected to the screen grid of *V4*. This connection utilizes the "push-pull" voltage produced at the plates of *V5* as a result of the coupling through the common cathode resistor (*R19*). Because of this common cathode coupling, equal and opposite changes in the voltages at the plates of *V5* take place when an antihunt signal is applied to grid 1 of *V5*. Grid 4 of *V5* is used to adjust the bias of one section of *V5* so that, in the absence of an antihunt signal, the plate currents of the two sections of *V5* are approximately equal.

ANTIHUNT LIMITER

The function of the antihunt limiter is to prevent the antenna from moving through and off the target when switching from manual to automatic tracking. Without antihunt limiting, the antihunt signal might overpower the error signal and cause the target to be lost.

Limiting is accomplished by connecting a double diode (*V6*) which receives the feedback signal to the grid of the antihunt amplifier. One half of the double diode conducts on large positive voltages, and the other half conducts on large negative voltages. The approximate voltages on the double diode with no antihunt signal are as follows: plate 3, −22 volts; cathode 8, −38 volts; plate 5 and cathode 4, −30 volts. The reference level of the antihunt voltage is also 30 volts. These voltages vary with the setting of the LIMITING CONTROL. When the peak of the feedback voltage becomes greater than 8 volts, either positive or negative, the diode conducts and prevents the feedback voltage from rising to a greater value.

QUIZ

1. During either conical or elliptical scanning, a pure azimuth pointing error is indicated when the
    - a. antenna axis is directly in line with the target.
    - b. reference voltages are 180° out of phase.
    - c. target is above or below the antenna axis.
    - d. target is directly to the right or left of the antenna axis.
2. The chief function of the d-c amplifier in the antenna-positioning system is
    - a. to limit the torque of the motor generators.
    - b. to minimize antihunt control.
    - c. to control the field currents of the motor generators.
    - d. none of the above.
3. Which tubes in the azimuth and elevation tracking unit protect the windings of the motor generators from excessive current?
    - a. Squarer.
    - b. Antihunt.
    - c. Commutator.
    - d. Torque-limiting.
4. The antihunt circuit is designed to eliminate oscillation by means of
    - a. negative feedback.
    - b. phase control.
    - c. positive feedback.
    - d. voltage limiting.
5. The antihunt circuit is incorporated in the azimuth and elevation tracking unit to
    - a. protect the windings of the motor generator.
    - b. prevent violent oscillation of the antenna about the on-target position.
    - c. limit error signal voltage to the synchro.
    - d. prevent variations in the strength of echo signals.
6. The magnitude of the error signal in the plate circuit of the error-signal amplifier of the automatic tracking unit is dependent on the
    - a. average height.
    - b. automatic gain control.
    - c. percentage of modulation of the video signals.
    - d. gain of the amplifier.

7. When the antenna is on target, the 30-cycle error output of the automatic tracking unit
   a. varies in phase only.
   b. varies in amplitude only.
   c. is zero.
   d. varies in amplitude and phase.

8. In the automatic tracking unit of the antenna-positioning system, the error signal amplifier output is a
   a. sine wave.
   b. square wave.
   c. d-c voltage.
   d. sawtooth wave.

9. In automatic tracking the reference voltage is produced by
   a. ship's generators.
   b. radar power supplies.
   c. reference generators coupled to the antenna shaft.
   d. reference resolver.

10. Negative feedback is NOT provided by
   a. a resistor and capacitor in series between the plate of one stage and the plate of the preceding stage.
   b. a resistor and capacitor in series between the plate and the grid of the same stage.
   c. a bypassed cathode resistor in the plate circuit.
   d. an unbypassed cathode resistor in the plate circuit.

True—False

11. The azimuth and elevation reference voltages are always in phase with each other.

12. When the axis of the antenna points directly at the target, the echo signals vary in amplitude for every position of the beam as it rotates about the antenna axis.

13. The output of the error signal and the reference voltage move the antenna in azimuth and elevation.

14. When the azimuth pointing error is such that the antenna must be rotated clockwise, the azimuth control voltage is a 30-cycle a-c voltage.

15. The azimuth and elevation tracking units are controlled by push-pull output of the balanced amplifier.

16. In figure 9–7, *V2* functions as the error-signal amplifier, and *V3* functions as the error-signal detector.

17. The secondary of *T1*, figure 9–7, is tuned to approximately 30 cycles by capacitors *C3* and *C4*.

18. The torque limiting circuit increases the control grid voltage of the d-c amplifier, which is sending excessive current into the motor-generator field winding.

19. The plates of the antihunt tube and the screen grids of the d-c amplifier are fed through separate dropping resistors so that an increase in current in the antihunt tube results in a lowering of voltage on the screen grid.

20. Without the antihunt limiting, the antihunt signal might overpower the error signal and cause the target to be lost.

CHAPTER 10

RADAR AUXILIARY CIRCUITS

POWER SUPPLIES

The amount of power necessary to operate radar equipment will depend upon the purpose for which the set is designed. All modern f-c radar systems are supplied with 440-volt, three-phase, 60-cycle a. c.; and 115-volt, single-phase, 60-cycle a. c.; unregulated, from the ships generators. High-voltage power supplies and regulated power supplies are, therefore, incorporated in each system.

Rectifier power supplies are used for relays and other control circuits applications, and in supplying all the various vacuum tubes in the radar set. Their efficiency will vary from 50 percent for a small unit to approximately 75 percent for the very large ones. From the maintenance point of view, a rectifier is more nearly trouble-free than is rotating machinery.

High-vacuum rectifier tubes have a life of from 1,000 to 4,000 hours depending on type and application, while the life of a mercury-vapor tube may be up to 15,000 hours. High-vacuum rectifier tubes are used where high voltages are required. These vary from the small receiver power supply which produces 250 volts to a large transmitter power supply which provides 15,000 volts. Mercury vapor tubes are used where a heavy current is needed and the voltages are from 700 to 5,000 volts. But they are not used for extremely high voltages because the inverse voltage may cause arc-back if the peak inverse voltage exceeds about 10,000 volts.

REGULATORS

Many types of regulators are used in radar sets. Manual regulators are usually either potentiometers, variable resistors, or variable auto transformers, such as variacs and transtats. Automatic regulators for holding the output voltages of a generator or other source of primary power at a desired value are usually mechanical in nature instead of electronic. Regulators are needed because all power sources have some internal resistance or reactance so that, as the load is varied, the output voltage of an a-c generator is controlled by adjusting the field rheostat of the exciter, which in turn varies the field current of the generator. Automatic voltage regulators control the generator by controlling the field of the exciter.

CONTROL DEVICES

Relay principles: A relay is a switch which is operated electromagnetically. It is designed to open or close a circuit when the current through its exciting coil is started, stopped, or varied in magnitude. The component parts of a relay are a coil wound on an iron core and an armature that operates a set of contacts. A simple relay and circuit are shown in figure 10–1.

In that figure (10–1) closing the operating switch S_1 allows current to flow through the coil, energizing the electromagnet and drawing the armature upward. The action of the arm-

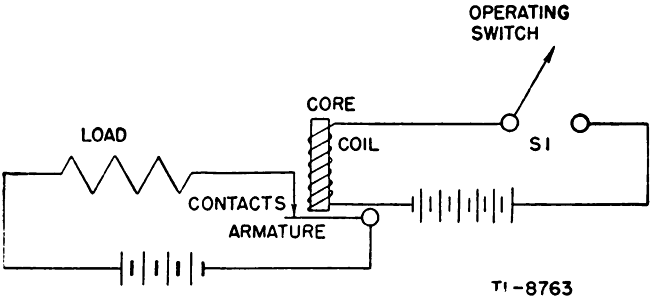


Figure 10–1.—Simple relay circuit.

ature closes the contacts thereby applying power to the load. More contacts can be added to the armature so that other functions may be accomplished.

The operating speed of a relay is determined by the time between the closing of the coil circuit and the closing of the relay contacts. The operating speed of a relay may be increased by reducing the eddy currents in the core, or by placing a resistor in series with the relay coil. This will increase the speed of closing because, at the instant power is applied to the relay, all the voltage will appear across the relay coil thus causing the magnetic field to build up faster.

Power relays or contactors: Heavy-duty relays called contactors are used extensively for remote-control electromagnetic switching. For these applications a relatively small amount of control power may be used to energize the holding coil of a contactor whose contacts are made heavy enough to handle any required amount of power. Such contactors are used in radar for applying power to electrical devices such as motors, filaments, and plate circuits of vacuum tubes. For the last-mentioned use, the contactor is normally connected in the primary of the filament or plate-circuit transformer.

Figure 10–2 shows a typical contactor of the clapper type. This contactor has a swinging armature pivoted at one end, with the contacts at the other. The clapper action causes

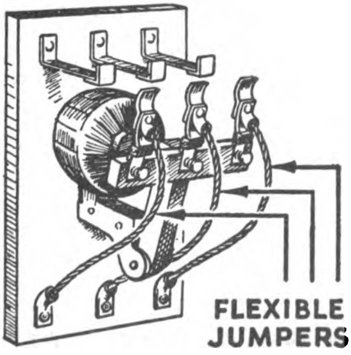


Figure 10–2.—Clapper type contactor.

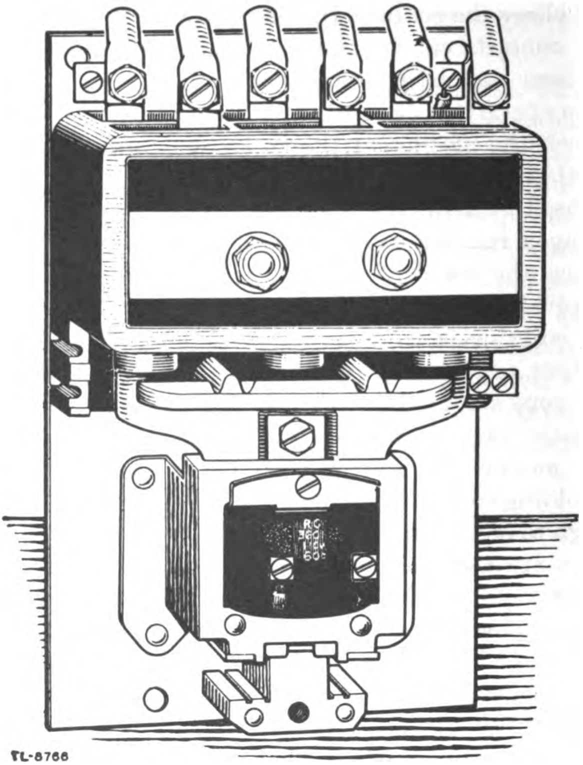


Figure 10–3.—Power contactor.

the contacts to come together with a sliding motion, which tends to make them self-cleaning.

Figure 10–3 shows a type contactor known as the solenoid relay, which operates with an up motion in the vertical plane. When the coil is energized, the plunger or armature snaps upward, closing the contacts. These are mounted on springs to insure an even pressure where more than one set of contacts is used. Contactors of this type usually have silver-alloy contacts which do not oxidize easily and require little maintenance.

CIRCUIT-CONTROL RELAYS

A circuit-control relay is used where the circuit functions become so numerous that operating switches for each would be complicated and time consuming.. Performing the functions with relays eliminates operational errors by causing the functions to take place automatically in their proper sequence.

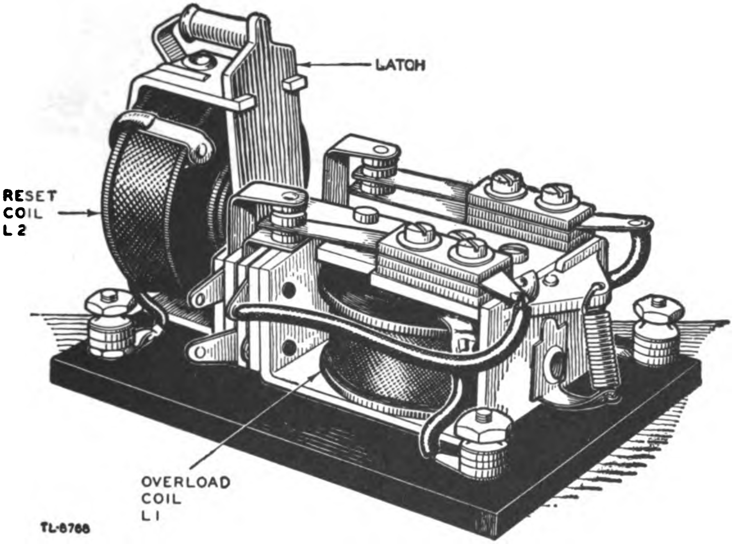


Figure 10–4.—Overload relay with magnetic release.

An overload relay is designed so that it will break a circuit when the current through it reaches a predetermined value. A latch is frequently provided to keep the circuit open following the overload, in order to prevent the circuit from being opened and closed repeatedly while the overload exists. An overload relay may have a push-button attached for mechanical release, or it may have an additional electromagnet for remote push-button release of the latch. The latter type of relay is shown in figure 10–4. Coil *L1* is connected in the plate circuit of the tube to be protected. Coil *L2* is energized momentarily to reset the mechanical latch after the overload relay has operated.

TIME-DELAY RELAYS

The time-delay relay is used to provide a time interval between separate operations. One common form of time-

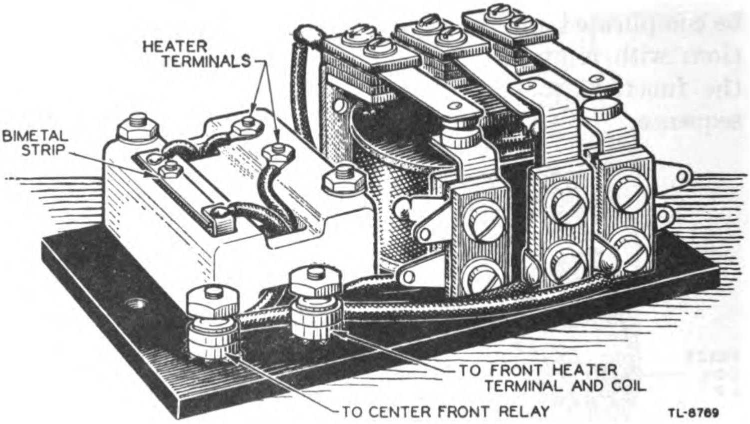


Figure 10–5.—Bimetal time-delay relay.

delay relay uses a bimetallic element which bends as it is heated. The element is made by welding together two strips of different metals having different expansion rates. A heater is mounted around or close to the element. Contacts are mounted on the element itself and, as the element is caused to bend by the different expansion rates, these contacts close to operate a relay (fig. 10–5). The delay time for bimetallic strips is usually from ½ to 1½ minutes and is varied by using metals with different expansion rates or by increasing or decreasing the distance between the fixed and moving contacts.

Motor-driven time-delay relays are frequently used. This type of relay employs a small synchronous motor and a gear train to obtain the desired delay time. A set of movable contacts is mounted on the last gear of the train and the circuit is closed when this set of contacts is turned enough to touch the stationary contacts (fig. 10–6). Other motor-driven time-delay relays utilize a spring action to close the relay contacts. The spring is released by the gear train after a given time interval.

CIRCUIT BREAKERS AND FUSES

Some form of protective device is needed in nearly all circuits. In primary circuits, where the voltage is fairly low

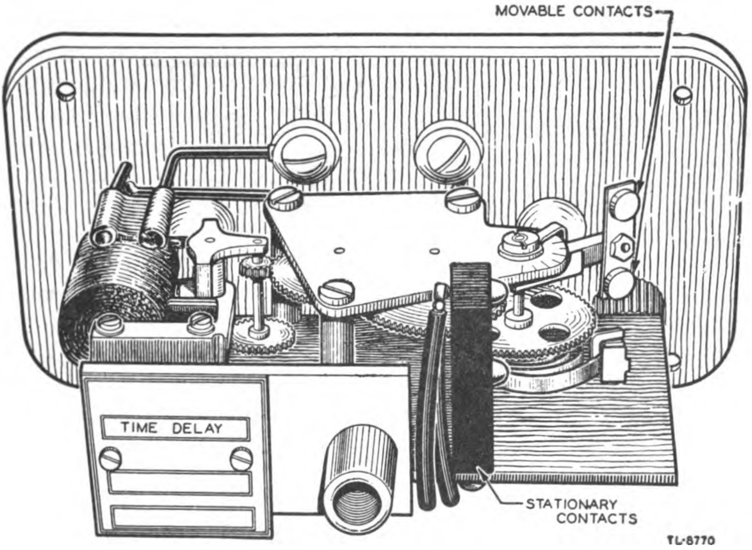


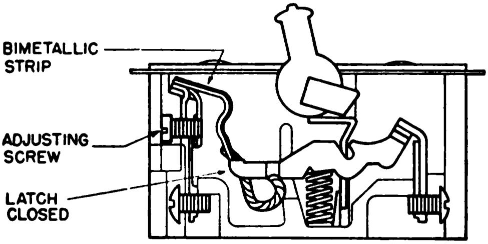
Figure 10–6.—Motor-driven time-delay relay.

and the current rather high, a circuit breaker or fuse is generally used, and in some cases both are used. These protect the source of power from overloads and short circuits, and also prevent the equipment from being burned out.

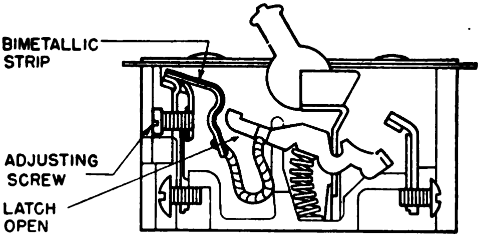
A circuit breaker is a switch that opens a circuit when a current of a certain limiting value flows through it for a given length of time. In the usual form, for radar primary circuits, the circuit breaker is operated by a heater element and bimetallic strip, or by passing current through the bimetallic strip itself to generate the heat. A typical circuit breaker is shown in figure 10–7.

Such a circuit breaker consists essentially of a carefully calibrated bimetallic strip, contacts, and a means of resetting. As current flows through this strip, heat is generated and the bimetallic strip bends. Under sufficient heat it bends enough to interrupt the circuit by releasing a trip, which opens the contacts.

The most common over-current device is a fuse. A fuse is merely a short length of wire or ribbon made of an alloy that



① ON POSITION



② TRIPPED POSITION

TL-8771

Figure 10–7.—Low-power circuit breaker.

has a low melting point and a size which will carry a given amperage indefinitely. But a larger current causes the metal to heat and melt, opening the circuit to be protected.

CONTROL CIRCUITS

The primary functions of control circuits are to provide convenient operation and to protect both personnel and equipment. Relays are used where it is impractical to close switches by hand because of location, voltage size, or number of switching operations to be accomplished. It is much more feasible to set up a control circuit, using relays to perform switching close to the components, than to bring leads carrying high voltage and heavy current to a more convenient operating position. A very important use of relays is to render high-voltage circuits inoperative, thus eliminating the possibility of personal injury when the circuits are not shielded or covered properly. Time-delay relays are used to protect expensive tubes from injury that would occur if the high-plate voltage were applied before the filaments had heated sufficiently. This tends to eliminate damage which would result from personal errors.

PUSH-BUTTON-OPERATED RELAY CIRCUITS

A relay may be operated from a separate power source by closing a switch, but, whenever possible, a push-button type control is used in combination with a holding circuit which keeps the current flowing through the relay coil after the push button is released. The hold-in is accomplished by a set of contacts on the relay itself which short the push button. The START button is normally in the open position. A STOP button is placed in series with the coil, which is normally closed. Whenever this button is pressed, the relay coil circuit is opened and the relay opens.

Figure 10–8 shows a simple push-button circuit that could be used to operate a filament transformer or other low power apparatus. When the start button is pressed, the relay is energized, closing the contacts. The action of the relay applies power to the load and provides a hold-in circuit to the relay, allowing the push button to be released. The relay can be opened by pressing the stop button, thus restoring the circuit to its original condition. This circuit has the dis-

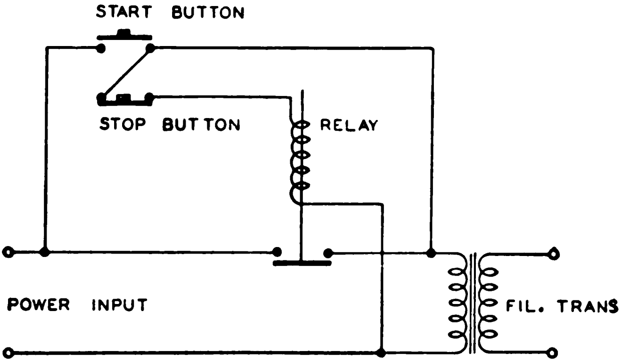


Figure 10–8.—Push-button-operated relay circuit.

advantage that the load current must pass through the push-button contacts between the time the button is pushed and the time the relay is closed. This limits the power handling capabilities of the circuit.

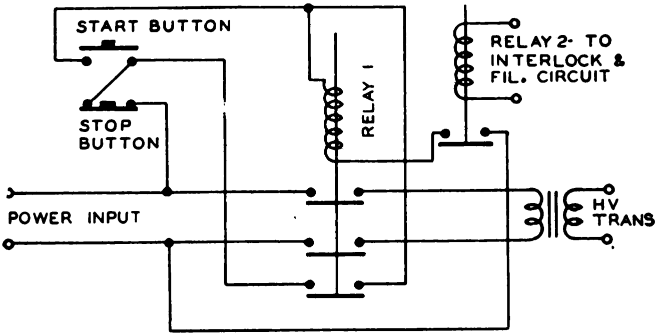


Figure 10–9.—Push-button-operated relay circuit.

Figure 10–9 shows a circuit suitable for a high-voltage power supply. This push button cannot operate relay 1 until relay 2 is closed. Relay 2 is operated by the filament and interlocked circuits. With relay 2 closed, relay 1 will close when the start button is pressed. An alternate path through the coil of relay 1 is provided by the lower set of contacts on relay 1 so that when the start button is released, relay 1 holds in. In this case the load current does not flow through the start button.

OVERLOAD PROTECTION

Some form of protection also must be provided for high-voltage equipment to prevent overloads caused by misadjustment, or to prevent damage to other components in case one fails. While a great many refinements may be added to overload relays, such as delay and automatic resetting mechanisms, the simple type is usually found in radar equipment. A circuit giving overload protection for a high-voltage system is shown in figure 10–10, which shows an overload relay circuit.

The overload relay is connected in the ground or low-

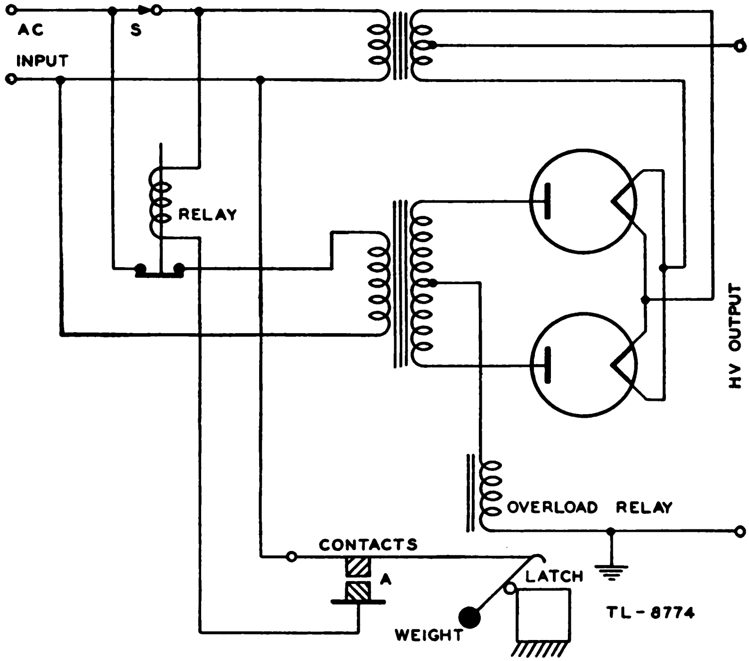


Figure 10–10.—Overload relay circuit.

potential side of the power supply to eliminate the necessity of high-voltage insulation. It is so adjusted that, when the current reaches a certain point, the armature lifts, opening the contact *A*. This opens the power-relay circuit and disconnects the primary of the high-voltage transformer. A latch is provided to prevent the armature from dropping and closing the contacts before the cause of the overload has been ascertained.

Some radar units use an over-voltage relay to protect the equipment from voltage surges caused by poor regulation. The coil of this relay is mounted in series with a spark gap. The two are placed between the high-voltage supply and ground with the coil at the ground end. When the voltage builds up to a value that is too high, an arc is formed across the spark gap causing current to flow through the relay. This opens the contacts and disconnects the high-voltage primary.

TIME-DELAY CIRCUITS

Time-delay relays are used in circuits to provide a definite time interval between operations. The most common use of the time-delay relay in radar is to allow a definite time to elapse after filament voltage is applied before plate voltage is turned on. A circuit of this kind is shown in figure 10–11. Power is applied to the filament circuit at the same time that power is applied to the heater unit of the time-delay relay, through its dropping resistor and the lower contacts of the time-delay relay. After the proper interval, the bimetallic strip bends sufficiently to close contacts *C*. Closing contacts *C* energizes both the holding relay and transformer to the power source. Operation of the holding relay disconnects the heater unit so that the bimetal strip may cool to the normal position to prevent the high voltage from being removed and suddenly reapplied. The holding relay keeps the high-voltage relay energized while the contacts *C* are open.

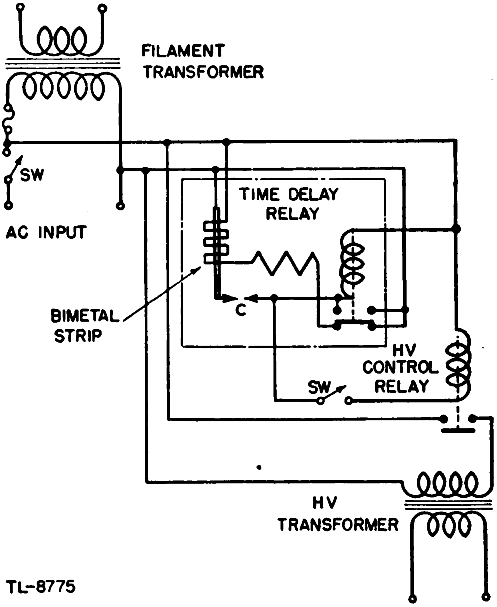


Figure 10–11.—Time-delay relay circuit.

INTERLOCK CIRCUITS

Interlock circuits are used in a radar set to prevent one unit from being turned on before another, where damage might occur if the proper order were not followed. Such circuits are also used to prevent high-voltage equipment from being turned on before protective covers are placed on the equipment to prevent personal injury. In the latter case switches are mounted behind the doors and panels in such a manner that they are closed when the covers are in place. The switches are placed in series with the holding coil of the high-voltage control relay. An interlock circuit is shown in figure 10–12. Power is applied directly to the filament supply and to the time-delay relay. After the time-delay relay has closed, power passes from point *A*, through the time-delay relay contacts, and then through the door and panel interlock switches. From here the current goes to the transmitter and passes through the contacts of a relay which is closed by applying power to the transmitter filaments. The current then passes through the overload relay and the high-voltage transformer control relay coil to the other side of the line. If all switches and contacts are closed, the control relay applies to the high-voltage transformer.

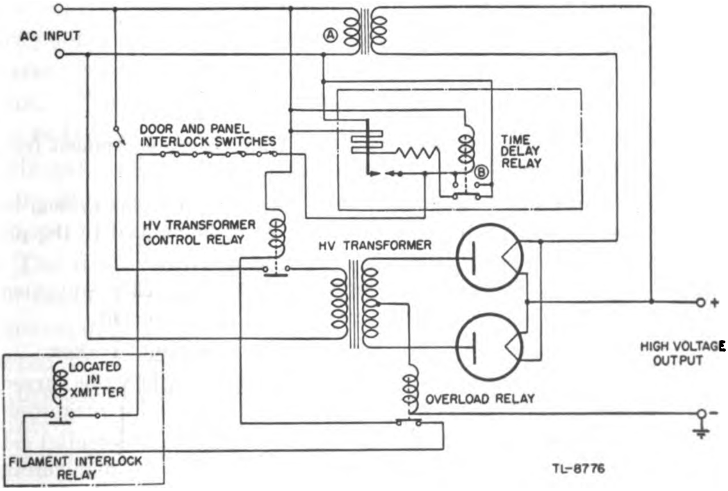


Figure 10–12.—Interlock circuits for high-voltage control.

QUIZ

1. A circuit control relay has the advantage of
   - a. causing circuit breakers to operate.
   - b. eliminating errors caused by throwing switches in the wrong order.
   - c. allowing for a time interval between separate operations.
   - d. working a switch more swiftly than by manual operation.
2. Manual regulators are usually either
   - a. potentiometers.
   - b. variable resistors.
   - c. variable auto-transformers.
   - d. all of the above.
3. An overload relay is designed so that
   - a. it may be opened by hand to break a circuit.
   - b. it will break a circuit when the current through it has reached a predetermined value.
   - c. its operation eliminates operational errors.
   - d. none of the above.
4. To allow for a definite time to elapse between the application of the filament voltage and the plate voltage, a special type relay is used known as a/an
   - a. interlock relay.
   - b. overload relay.
   - c. time-delay relay.
   - d. push-button relay.

True—False

5. Interlock circuits are used to prevent high-voltage equipment from being turned on before protective covers are in place.
6. To prevent high voltage from being applied to a radar system before the filament voltage, an overload relay is coupled to the primary circuit.
7. The primary function of control circuits is to provide convenient operation and to protect both personnel and equipment.
8. The most common over-current device is the circuit breaker.
9. A relay is designed to open or close a circuit when the current through its exciting coil is started, stopped or varied in magnitude.
10. The overload relay is connected to the ground or low-potential side of the power supply to eliminate the necessity of high-voltage insulation.

CHAPTER 11

RADAR BEACONS

A radar beacon is a device that receives a radar pulse, amplifies it to trigger its own transmitter, and thus transmits a reply to the original radar. The beacon transmitter can be very low in power because the radar receiver is sensitive enough to receive echo signals that are much weaker than the original transmitted signal. A radar beacon is a passive device; that is, it is normally quiescent and does nothing until it is triggered by an external signal.

Radar beacons are used in conjunction with fire-control radar to provide reference points near a target. The beacons are placed by aircraft or shore fire-control parties.

Radar beacons are also used to obtain navigational fixes by fire-control radars, to vector landing craft through mined waters, and in boats to direct fire against nearby shore targets. They are used as targets for aligning or boresighting f-c radar as well as in aircraft that fly over a target to provide range and bearing data to the f-c radar aboard ship. They can be used in establishing the front line of advancing troops.

The Radar Beacon Mark 2 is used in conjunction with the f-c Radar Mark 12. It is a low-powered receiver-oscillator (transpondor) that transmits a pulse each time it is triggered by a pulse from the fire-control radar aboard ship. Since the beacon signal is received and displayed by the fire-control radar, the beacon is designed to operate at the same frequency. Hence, no interrogator-respondor equipment operating at its own frequency is necessary.

UNITS AND OPERATION

A functional block diagram of a radar beacon is shown in figure 11–1. The antenna receives the challenge signal from the fire-control radar and injects it into the superregenerative receiver, *V2*. The receiver both amplifies and detects the challenge pulse.

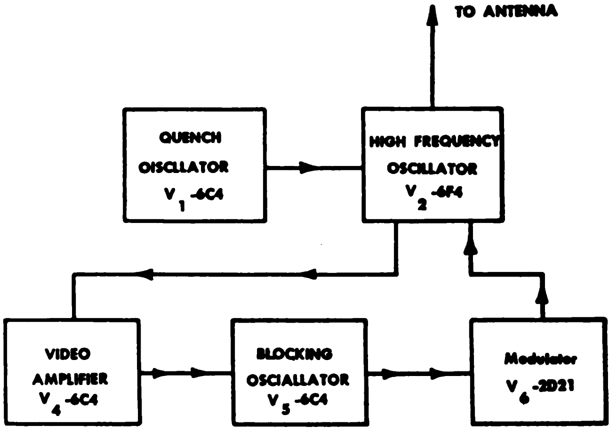

TO ANTENNA
QUENCH OISCLLATOR V_1-6C4
HIGH FREQUENCY OSCILLATOR V_2-6F4
VIDEO AMPLIFIER V_4-6C4
BLOCKING OSCIALLATOR V_5-6C4
Modulator V_6-2D21

Figure 11–1.—Functional block diagram of Radar Beacon Mark 2 Mod 1.

The video pulse is amplified in video amplifier, *V4*, and triggers a blocking oscillator, *V5*. The blocking oscillator triggers the modulator, *V6*.

The modulator delivers a 0.75-microsecond pulse of high voltage to *V2*. The modulator pulse causes *V2* momentarily to stop functioning as a superregenerative receiver and to oscillate as a low-powered transmitter.

Antenna

The antenna of the Radar Beacon, Mark 2, Mod 1 is a corner reflector made of several rods. The array has a power gain of 10. The beamwidth is approximately 60° in the vertical plane and 90° in the horizontal plane. This cuts down back radiation and minimizes the danger that the beacon may be located by use of radio direction-finding devices in the hands of the enemy.

Receiver

The receiver of the Mark 2 Beacon is a superregenerative receiver. Tube *V2*, figure 11–1, is a high-frequency oscillator which is turned on and off at a lower frequency by the quench oscillator, *V1*. A characteristic of the superregenerative receiver is tremendous amplification and simultaneous detection within a single tube.

Tube *V2* is both the receiver and the transmitter. As a receiver, it is a self-sustained oscillator. Its oscillations are quenched before they build up to a maximum. A received signal of not less than 2×10^{-9} watts is necessary to actuate the blocking oscillator, which causes a 600-volt pulse to be applied to the high-frequency oscillator *V2*. When this occurs, tube *V2* does not function as a receiver but as a plate-modulated transmitter.

The sensitivity of the receiver depends on both the characteristics of the high-frequency oscillator, *V2*, and the quench voltage applied to its grid. The quench voltage turns the oscillator on, but not long enough to allow the oscillations to reach maximum amplitude.

In a superregenerative receiver the signal can be received only on the peaks of the quench voltage, and the receiver is insensitive between peaks. Therefore, it is necessary for the received signal to have a duration at least as long as the space between quench peaks to prevent the signal from falling on the insensitive period of the receiver. In the Mod 0 the quench frequency is 625 kc., or one cycle in 1.6 microseconds. In the Mod 1 the quench frequency is 900 kc., with 1.1 microseconds between receiving periods.

High-frequency Oscillator

The Colpitts oscillator, *V2*, uses a half-wave coaxial line tank. The circuit and the equivalent oscillatory circuit are shown in figure 11–2. This figure indicates how the inter-

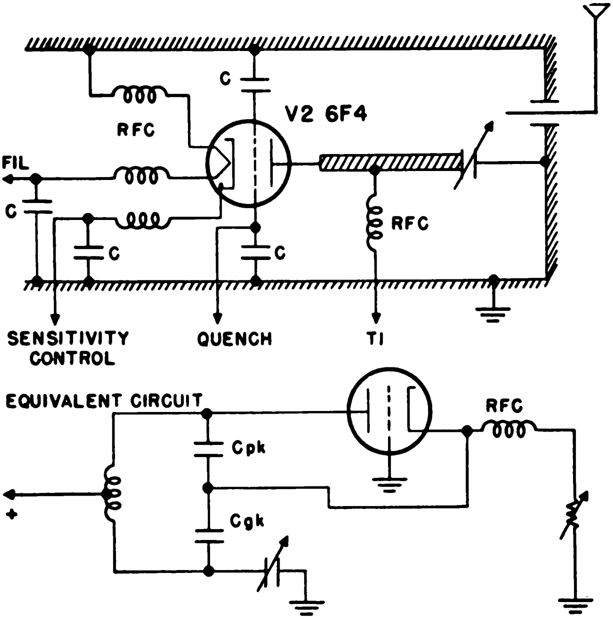


Figure 11–2.—High-frequency oscillator.

electrode capacities of the tube form an equivalent circuit.

To adjust for maximum sensitivity, the amplitude of the quench voltage in a h-f oscillator is maintained at a fixed level and the characteristics of the oscillator are varied. This is done by the sensitivity control, which changes the bias on the oscillator. This adjustment also takes care of circuit variation, such as changes in antenna loading, tuning, and tube characteristics.

Quench Oscillator

The 25-volt quench voltage applied to the grid of the oscillator is produced by a triode, *V1*, used in a Hartley-oscillator circuit as shown in figure 11–3. *L1* is the inductance that determines the quench frequency. Grid current through *R1* determines the bias on *V1*. The negative 105-volt supply is regulated. The fixed-level quench is

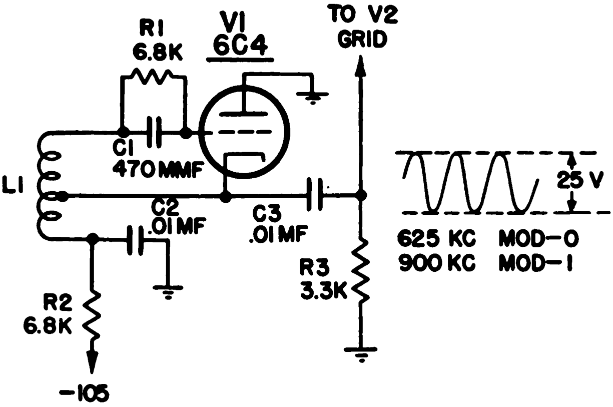


Figure 11–3.—Quench oscillator.

necessary to keep the sensitivity of the receiver relatively constant throughout the life of the 6-volt storage battery used as the primary source.

Video Amplifier

When receiving, the output of the high-frequency oscillator *V2* is applied as a positive pulse to the video amplifier *V4*. The positive input pulse is amplified and appears in the plate circuit of the amplifier as a negative pulse. Figure 11–4 shows the circuit of the video amplifier.

Blocking Oscillator

The negative pulse from the video amplifier, *V4*, is reversed in the transformer *T2* and applied to the grid of the blocking oscillator, *V5*, as a positive pulse. This positive pulse overcomes the negative bias voltage and sets the blocking oscillator into operation. The blocking oscillator is a regenerative amplifier in which the period of regenerating is controlled by the blocking capacitor, *C6*. Figure 11–4 shows the circuit of the blocking oscillator.

The tube *V5* is biased by the voltage divider, *R9* and *R10*, so that it requires a definite signal before it draws current.

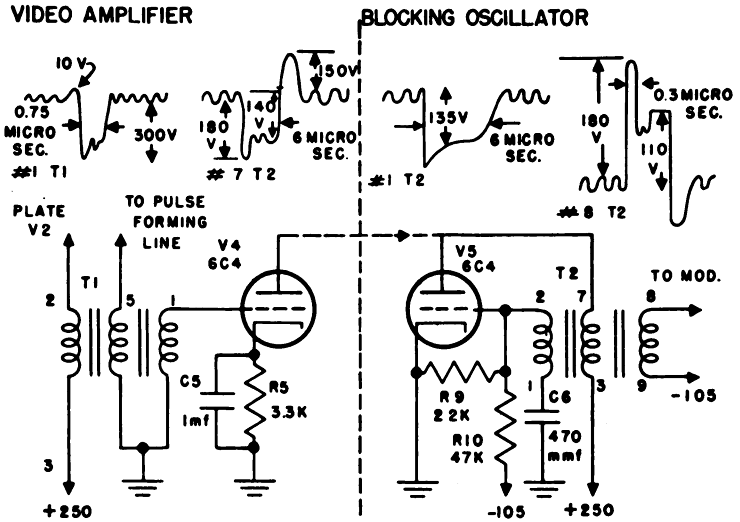


Figure 11–4.—Video amplifier and blocking oscillator.

When the signal from the video amplifier causes this to happen, a negative voltage is developed across the plate winding of the blocking oscillator transformer *T2*. This voltage is reversed in polarity in a second winding and applied to the grid, producing the regeneration. The regeneration takes place during the period it takes to charge the blocking capacitor, *C6*. After that time the tube resumes its quiescent state until another signal is received.

The output of the blocking oscillator is taken from a third winding in the transformer, *T2*, and applied to the grid of the modulator as a positive pulse.

Modulator

The modulator tube, *V6*, is a 2D21 thyratron. It is normally deionized by the negative 105 volts. It is ionized when triggered by the positive pulse from the blocking oscillator. Figure 11–5 shows the circuit of the modulator.

The modulator delivers a pulse to the plate of *V2*. The pulse has a duration of 0.75 microsecond and a peak amplitude of 600 volts. This pulse is formed by charging the pulse-forming line to the operating voltage of 250 volts, and then instantaneously discharging the line through the modulation transformer *T1*. The line, consisting of a series of inductors and capacitors, is designed to produce a 0.75 microsecond pulse. The peak power depends on the voltage, the total capacity charged, and the time, 0.75 microsecond, in which the line is discharged. The line is designed so that 40 percent of the voltage of the charged line appears across the primary of the modulation transformer *T1*. The voltage is stepped up six times in the transformer and applied to the plate of the oscillator *V2*.

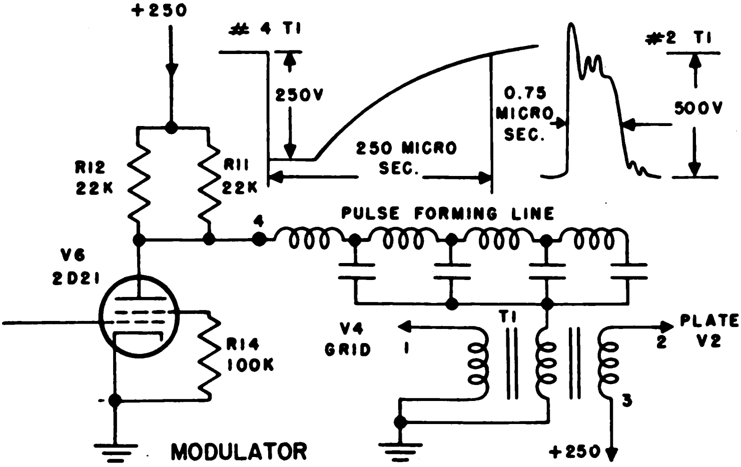


Figure 11-5.—Modulator circuit.

The switching operation that discharges the line is produced by the 2D21 thyratron tube. When deionized, the plate impedance of the tube is high. When the grid is triggered positive, the tube is ionized and has an extremely low impedance between the cathode and the plate. The tube remains in this condition during the discharging period of the line. After discharging the line, the tube requires approximately 100 microseconds to assume its normal deionized condition.

Transmitter

The coaxial-line oscillator, *V2*, stops being a receiver and becomes a transmitter when the modulator supplies the 600-volt, 0.75-microsecond pulse to the plate of the oscillator.

When the 600-volt pulse is applied to the plate, the oscillator is thrown out of its superregenerative state and acts as a plate-modulated oscillator. The output, coupled into the antenna, is approximately 15 watts of peak r-f power in the form of a 0.75-microsecond pulse.

Power Supply

The primary power source of a radar beacon is a 6-volt storage battery. The operating voltage of the beacon is supplied by a dynamotor that delivers 350 volts. By use of a regulator tube, *V3*, the output of the dynamotor is divided to provide a positive 245 volts for the plate voltage and a negative 105 volts for the bias.

QUIZ

1. During transmission from the Radar Beacon Mk 2, which tube acts as a plate-modulated oscillator?
   a. *V1.*
   b. *V2.*
   c. *V5.*
   d. *V6.*

2. What is the primary source of power used for the Radar Beacon Mk 2 Mod 1?
   a. The ship's 110-volt a-c line.
   b. A 24-volt storage battery.
   c. A 6-volt storage battery.
   d. The ship's 220-volt a-c line.

3. How does the thyratron of the Radar Beacon Mk 2 Mod 1 modulate the 6F4 oscillator?
   a. By coupling the pulse-forming line to the oscillator for the duration of the pulse.
   b. By discharging the line through pulse transformer *T1*.
   c. By charging the pulse-forming line to +250 volts.
   d. By deionizing, and thereby connecting the oscillator through pulse transformer *T2* to the pulse-forming line.

4. The Radar Beacon Mk 2 is employed with which of the following radars?
   a. Mk 8.
   b. Mk 12.
   c. Mk 13.
   d. Mk 32.

5. Which of the following statements concerning the blocking-oscillator transformer used in the Radar Beacon Mk 2 Mod 1 is NOT true?
   a. The blocking oscillator output is taken from the third winding and applied to the modulator grid as a positive pulse.
   b. A negative pulse from the video amplifier is stepped up to a higher voltage and applied to the grid of the blocking oscillator as a negative pulse.
   c. A negative voltage is produced across the plate winding when the signal from the video amplifier causes the blocking oscillator tube to draw current.
   d. A positive voltage is generated in the second winding and applied to the grid of *V5*, resulting in regeneration.

6. The quench frequency of the Radar Beacon Mk 2 Mod 1 is
   a. 625 kc.
   b. 750 kc.
   c. 900 kc.
   d. 1100 kc.

True—False

7. To reduce back radiation of the Radar Beacon Mk 2 Mod 1, the beamwidth of the antenna is made approximately 60° vertical and 90° horizontal.

8. Beacons are used to provide the fire-control radar aboard ship with known reference points.

9. The modulator tube, *V6*, is triggered by the positive pulse from the blocking oscillator.

10. The quench frequency is determined by the inductance of *L1*.

CHAPTER 12

RADAR MAINTENANCE AND TEST EQUIPMENT

Preventive maintenance involves periodic inspection, overall cleaning and lubrication, checking of brushes, cleaning and tightening of contactors, adjusting and calibrating of electronic circuits, and checking of system performance.

Specific schedules of preventive-maintenance operations are listed in each system instruction book. Many of these operations may be performed by well-trained radar operators. This is particularly true whenever the work can be reduced to simple routine operations that can be performed by men with limited technical background.

The attention of the radar operators should be directed toward the study of electronic theory and in the practice of troubleshooting, that the ship may gain capable operators as well as technicians.

However, technicians should frequently check any routine measurements being made by the operating personnel, and they should be responsible for any preventive-maintenance adjustments and measurements that require technical knowledge and skills to perform adequately and safely.

CORRECTIVE MAINTENANCE

When preventive-maintenance tests show that a radar operates inefficiently, or when inspections show that a radar needs repairs or modifications, mechanical and electrical adjustments or the replacement of one or more parts may be necessary. Most corrective maintenance is performed only by qualified technicians.

Troubles in radar systems are found by a process of localization, which consists of system troubleshooting and unit troubleshooting. System troubleshooting involves an understanding of the organization of the major radar system as consisting of several interrelated minor systems.

If trouble develops in one of the minor systems, the major system cannot perform all the functions for which it was designed. In some radars a single fault is sufficient to render a minor system inoperative. In other radars the initial failure of one part (such as a capacitor) may result in the failure of many other parts, all of which must be replaced before the radar will operate again.

In order to simplify the task of locating troubles, a radar is subdivided into its minor systems as follows:

1. Primary power and control system.
2. Transmitter system.
3. R-f transmitting or "plumbing" system.
4. Receiving system.
5. Indicating system.
6. Antenna-positioning system.

Some of these systems depend in some respects on one or more of the other systems. For example, if there is no trigger output from the transmitter system to the indicator system, the indicating system cannot function even if the transmitting system is operating normally in other respects. Just because a minor system is not operating does not always mean that the trouble is in that system. The trouble may be in a unit that furnishes the input signal or in the cabling that connects the two units. Therefore, it is necessary to analyze carefully each situation in order to locate the system at fault. If this is not done, much time may be lost in checking a system that is capable of normal operation if proper input voltages are available.

A careful analysis of trouble also helps to prevent the form of panic that is expressed in the twisting of all accessible screwdriver adjustments in the hope that "operation will be improved." Haphazard tampering with adjustments cannot improve overall performance, and may possibly turn a minor repair problem into a job of major overhaul requiring special instruments or naval yard availability. Follow the specific method for system troubleshooting given in the radar instruction books. All technicians should be thoroughly drilled in the use of troubleshooting charts and specific procedures of system analysis which are given in equipment instruction books.

The ability to analyze system troubles requires basic knowledge of electronics, and must be further developed by additional study of integrated radar systems. The development of good habits of analysis can be helped considerably by discussion and circuit study in study groups.

An analysis of the system should be followed immediately by a further analysis of the defective unit so as to locate the faulty part.

USE OF OSCILLOSCOPES

Many radar timing circuits are designed to produce electrical pulses of precise duration and of distinctive waveform. It is therefore obvious that a device by which waveforms can be observed and measured is a valuable instrument in corrective maintenance. These distinctive waveforms are provided in most modern instruction books. The technician should check all test points for which waveforms are given. He should check them when the radar is operating perfectly and should note any discrepancies between the operating equipment and the instruction book. Let us consider a specific oscilloscope.

TS–239/UB: This oscilloscope has built-in calibration potentials and an internal trigger-pulse generator which also supplies external pulses of 4 microseconds duration at a potential of 25 volts. Three pulse-repetition rates are possible. The scope sweep can be synchronized internally with the triggering pulses. This instrument is thus actually a synchroscope, which is an oscilloscope that embodies the usual oscilloscope circuits with the addition of trigger, marker, and delay circuits to vary the relation between the trigger pulse and the start of the sweep. The accuracy of the built-in timing circuits can be calibrated readily against external oscillators of known accuracy. Any oscilloscope can be used in the examination of radar timing pulses. This is the purpose for which it is most frequently used.

Some radars are equipped with built-in test scopes. Others have the more significant test points connected to a multipoint switch, which in turn connects to a test jack for an external test scope. Such schemes permit rapid checking of performance by operating personnel and technicians. Critical adjustments are frequently made with scope patterns for guidance. In still other types of radar an indicator scope may do double duty as a test scope when provided with test leads and when the radar signal input is switched off.

RADAR ECHO BOX

The echo box is an integral part of some shipborne radars, and separate echo boxes are available for use with others. An echo box provides a "standard echo" which may be used for comparison whether real targets are present or not; duct propagation effects are thereby eliminated. By the inclusion of a simple power-indicator circuit in the echo box, the power of the transmitter may be measured separately from the sensitivity of the receiver, and the cause for poor operation may be quickly located in one of those two components. If an arrangement is made to switch the coupling of the echo box between a waveguide pick-up and an external pick-up antenna, poor operation resulting from a defective antenna or transmission line can be readily detected.

The echo box is essentially a tuned cavity that is coupled either to the antenna waveguide by means of a directional coupler, or to the antenna field by a simple pick-up antenna. Energy from the transmitter pulse enters the pick-up and oscillation is induced in the resonant cavity of the echo box. This oscillation can be sharply tuned to the transmitter frequency. This coupling is shown in figure 12–1.

Because the resonant cavity of an echo box has a very high Q and is loosely coupled to the antenna, its oscillations are not dampened out at once, but continue to "ring" within

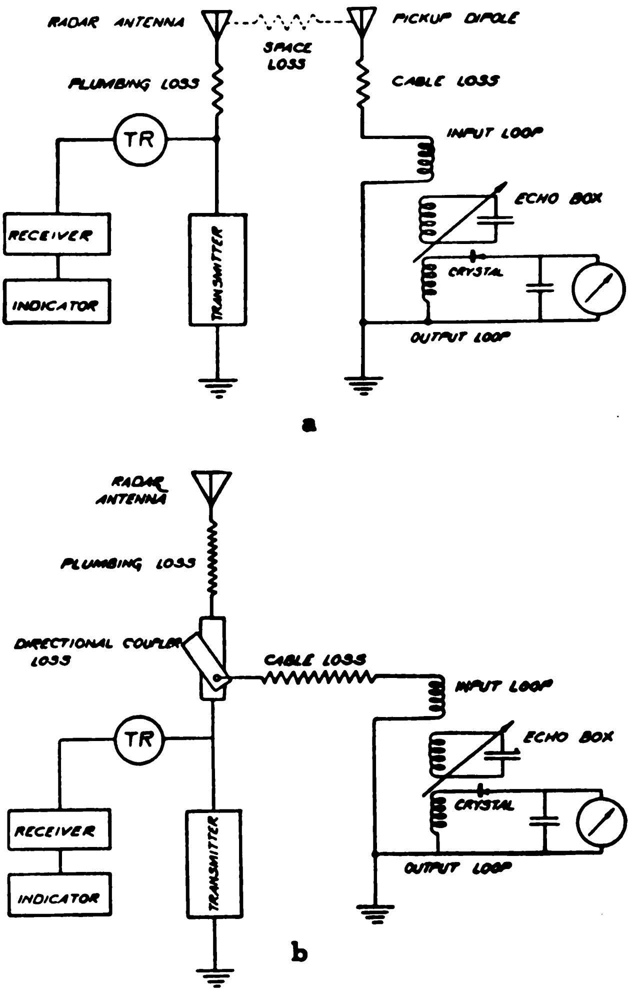
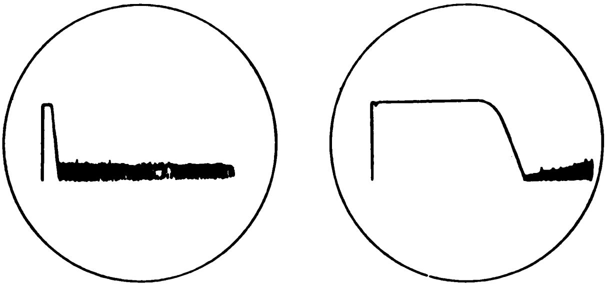


Figure 12–1.—Equivalent circuit of an echo box.

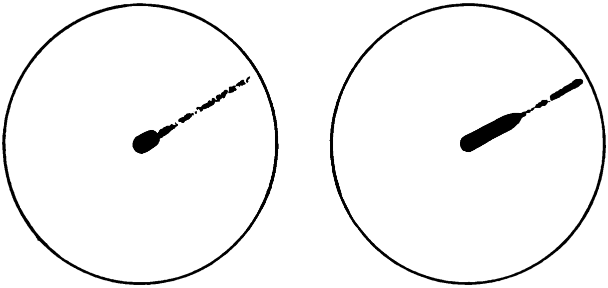
the cavity. A small amount of energy is reradiated during this ringing time from the pick-up antenna and is received by the radar receiving circuits as an elongated main bang. See figure 12–2.

With most modern fire-control systems another type of echo box is provided as a standard piece of equipment to the system. This radar echo box is an untuned ringing cavity and is used to provide an artificial or phantom target to tune the receiver to the transmitter frequency in case real targets are not available. A short length of r-f cable is excited by a portion of the energy generated by the transmitter; it exhibits the property of sustaining oscillations which appear as a damped train of oscillations following the output pulse. These oscillations contain frequency components of the transmitter pulse and can therefore be used as an artificial target echo. The oscillations from the echo box are detected by the radar receiver and show up on the indicator scope as an extension of the transmitted pulse. The response, called the RINGING TIME, can be measured in radar yards by the range unit.

The receiver of the radar should be tuned for maximum ringing time, and the maximum signal should occur at maximum crystal current. Checks of ringing time should be



ECHO BOX DETUNED CLASS A ECHO BOX TUNED



ECHO BOX DETUNED CLASS PPI ECHO BOX TUNED

Figure 12–2.—Couples echo box showing the effect of receiver nonrecovery.

made when the system is known to be operating properly and should be recorded for use in future tests. The echo box may also be used to give an approximate output power relative to some arbitrary standard.

RINGING TIME: Since ringing time on a scope is delayed on a range scale, it is customary to speak of its measurement in yards instead of microseconds. The ringing time of a transmitter depends on the following factors: (1) transmitter peak power, (2) receiver sensitivity, (3) losses of either transmitter power or signal power (such as losses caused by mistuned or defective TR and ATR tubes), (4) pulse length. (5) transmitter spectrum, (6) coupling losses, and (7) echo-box sensitivity.

If all other factors are constant, the amplitude of the oscillations in the echo box increases as the peak power of the transmitter increases. Therefore, it requires a longer time for these oscillations to die down and, consequently, the ringing time is increased. Similarly, the lower the receiver input noise level, the longer the ringing time since the weaker signals issuing from the echo box at the trailing end of the ringing time may be seen and measured. If the noise level is high, these faint oscillations do not appear on the scope as is shown in figure 12–3. In this figure note that the receiver gain has been adjusted so that the grass is a quarter to a third of the total saturated signal height on the scope.

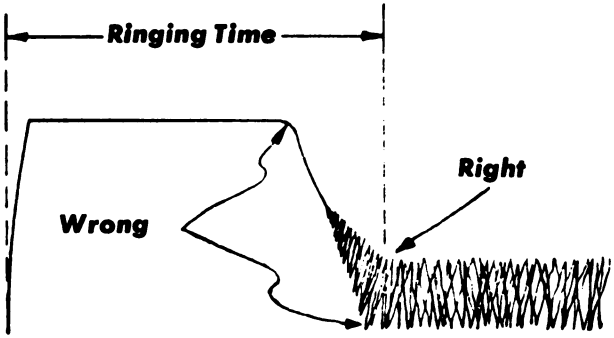


Figure 12–3.—Appearance of good ringing time displayed on an A scope, showing correct and incorrect points to which ringing time is measured.

It should be pointed out here that the receiver noise level can be attributed to two principal factors—the receiver noise figure and the receiver bandwidth. Of these two, the noise figure, which determines the general figure of merit of receivers, is the quantity that you are trying to minimize when tuning a receiver. The noise figure can be defined as the noise per unit bandwidth in a receiver relative to the noise that would be present in a theoretically ideal receiver with the same amplification factor.

The receiver bandwidth, which does not ordinarily change, also contributes to the noise level. The wider the bandwidth the more noise is permitted to pass. Therefore, a decrease in the bandwidth that might impair the performance of the radar could possibly increase the ringing time. When a receiver oscillates because of interstage feedback, the bandwidth is greatly reduced and the ringing time is increased somewhat. Oscillation can be recognized by a coarseness of the grass, by a tendency of the gain to increase abruptly at a particular gain-control setting, and by a slightly less abrupt drop than is common in the end of the ringing time. Since in radar design the bandwidth is adjusted to suit the pulse length used, there is an interrelationship between these two factors, each of which separately influence the ringing time.

The pulse length and transmitter spectrum affect the ringing time. The longer the pulse the greater the ringing time since the echo box charges up to a greater extent for a longer pulse. A "bad" spectrum affects ringing time in that power applied to the narrow bandpass of the echo box may be reduced because the transmitter energy is scattered over a wider range. Radar performance, and therefore ringing time in this case, may be affected by the scattering of the transmitter energy outside the receiver bandwidth, by impaired signal shape and by inoperative AFC.

Other factors such as the coupling connecting the box and the radar, the loss in the cable connecting the box to the directional coupler, and the echo-box sensitivity also affect the ringing time. If the losses in the coupling elements are low and the box sensitivity is high, the ringing time is increased, and vice versa. An efficient type of coupling frequently used between the radar and the echo box is the directional coupler, which enables the use of a fixed known amount of radar power for test purposes. This coupling also permits the echo box to be located near the main frame. Echo-box sensitivity is defined as the change in ringing time that corresponds to a given change in radar performance. This is nominally a constant for a given type of echo box, but it varies with frequency, temperature, and the individual echo box, necessitating correction of the nominal value for an accurate determination of sensitivity in a particular case. The method of calculation of sensitivity of a particular box at a known frequency and temperature is given in the instruction book.

PRECAUTIONS IN MEASURING RINGING TIME.—Since ringing-time measurements constitute the most valuable single feature of the echo box, it is essential that they be carried out properly and with due regard for the necessary precautions.

In measuring the ringing time the technician should make sure that it is the echo-box ringing time and not some target echo or block of echoes that is being received. This can be determined by adjusting the radar gain control and noting whether the ringing time moves back and forth. When the gain control is adjusted, target echoes change in amplitude but not in range. The echo box, however, changes in range.

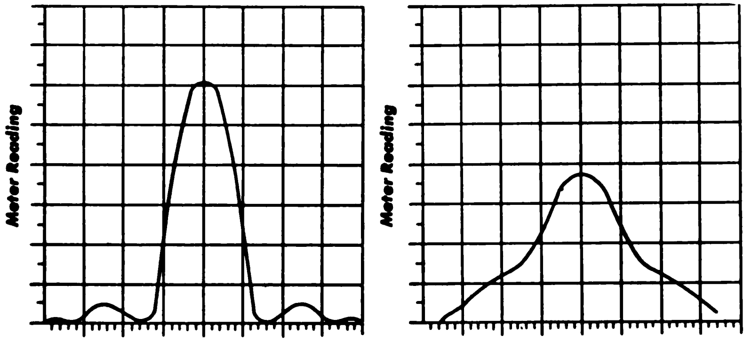
To obtain accurate results, the technician should repeat every ringing-time measurement at least four times and should average the readings. He must be careful to make all readings as accurately as possible. If two or more persons use the same echo box, they should practice together until their ringing-time measurements agree.

The radar has a tendency to drift slightly in frequency. When this occurs the echo box becomes detuned and accurate ringing time measurement is difficult. It is therefore necessary, when ringing time measurements are being made from time to time, to retune the echo box every few minutes.

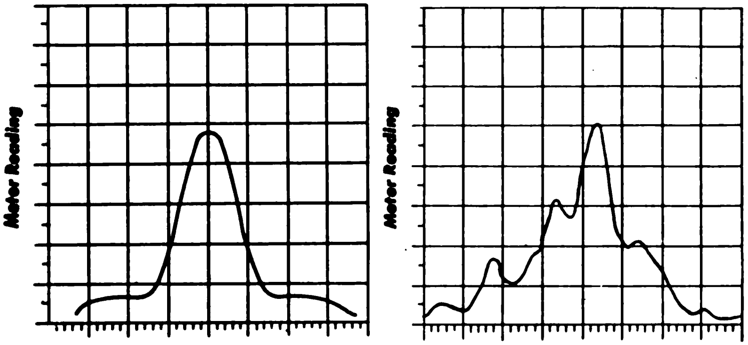
The radar antenna should not be pointed at a mast or other nearby obstructions as this may cause the transmitter to change frequency.

SPECTRUM ANALYSIS

The spectrum of a pulse is the frequency distribution of its energy. This spectrum can be obtained by plotting the echo-box meter readings with the box tuned to various frequencies. Typical spectra are shown in figure 12–4. The variance of curve (c) from curves (a) and (b) may be caused by: (1) an unstable transmitter tube, (2) operation of the transmitter tube with improper voltage, current, or magnetic field, or possibly (3) the application of a high-voltage pulse of incorrect shape to the transmitter tube. Severe irregularities, as in curve (d), may be caused by a large standing-



a. Good Spectrum *c. Poor Spectrum*



b. Fair Spectrum *d. Bad Spectrum*

Figure 12–4.—Typical radar spectra.

wave ratio in the transmission line because of a faulty line connection, a bad antenna rotating joint, or obstructions in the line.

RADAR RANGE CALIBRATION

Radar indicators include stable timing circuits. These circuits must be calibrated to insure accuracy or range indications. At sea, the double-reflection echo method may be used to calibrate the indicator zero setting, or comparison with an object at a known range may be used for the same purpose.

DOUBLE ECHO: Before any adjustments are made, when the double-echo method of calibration is to be used, the radar should be allowed to warm up for at least 30 minutes. The ship should assume and maintain a broadside position with respect to the target ship about 1,000 to 2,000 yards distant. (No other ship or object should lie nearer than 5,000 yards beyond the target ship). Under these conditions a weak second-target pip ordinarily appears at twice the target range. Since no time lag occurs between first and second pips, the distance between pips is the range of the target from the ship, and the RANGE ZERO SET adjustment may be varied to make the range counter read this correct amount when the start of the echo just touches the range line or step.

TARGET OF KNOWN RANGE: Choose an isolated target—the range of which is 3,000 yards or more and is precisely known—from which good echoes can be received, to use this method of calibration. A radar corner reflector sometimes is mounted on a convenient low island for use as a calibrating target. With the counter dial set at the accurately known distance, adjust the RANGE ZERO SET to make the start of the target echo just touch the range line or step.

USE OF TS–33/AP FREQUENCY METER

The frequency meter TS–33/AP is used for measuring frequencies in the *X* band of either pulsed or c-w signals.

The electrical circuit of this meter includes a coaxial line cavity which is tuned by means of a micrometer-driven plunger. A crystal detector is used with a d-c microammeter to indicate resonance when measuring the frequency of a c-w or pulsed signal, resonance being indicated by a dip in the meter reading.

An external oscilloscope can be used, instead of the d-c meter, when measuring the frequency of a pulsed signal. The d-c meter, including shunt and multiplier arrangements, may be switched to the video jack for use as a milliammeter or voltmeter.

The high-frequency input connection consists of a 42-inch length of coaxial cable coupled to a waveguide through a waveguide transformer. The waveguide is probe-coupled to the coaxial cavity. Adapters are provided for connecting the cord to the radar converter cavities or for use as antennas if desired. The power applied to the detector is regulated by means of an 0–35 db attenuator. The crystal detector is mounted in the waveguide with associated impedance matching reflector plate. A calibration chart is provided to translate the micrometer reading into changes of frequency.

RADAR TEST SET TS-147/UP

Tests may be made separately on radar elements by means of a microwave signal generator, an oscilloscope, and suitable frequency and power-level meters. One such test set, TS–147/UP, is designed for testing beacon equipment and radar systems that operate within the frequency band of 8,500 mc. to 9,600 mc.

Figure 12–5 is a block diagram that shows the interconnection of each part of test set TS–147/UP. The test signals are generated by a reflex-klystron oscillator which is frequency-modulated by the sawtooth voltage supplied by the triggered sweep generator. The sweep generator is triggered in synchronism with the radar-system firing cycle, either by means of voltage pulses connected to the TRIGGER IN receptacle, or by pulse r-f power detected and amplified by the detector crystal and trigger amplifier.

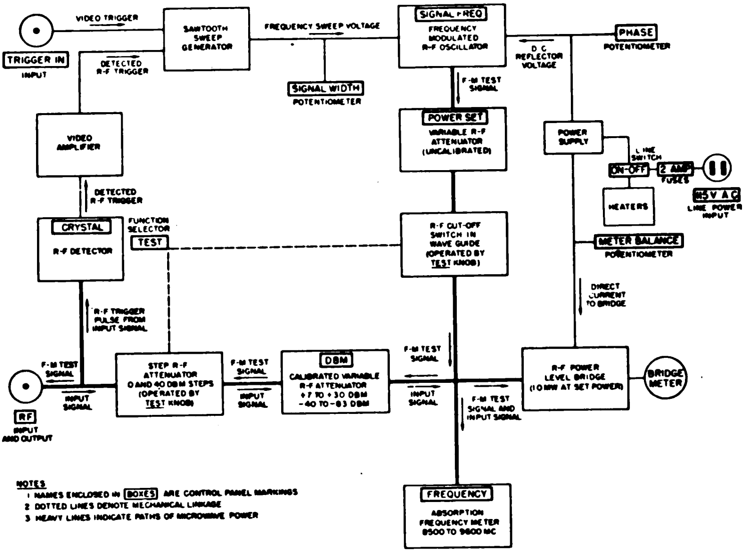

VIDEO TRIGGER
TRIGGER IN
INPUT
SAWTOOTH SWEEP GENERATOR
DETECTED R-F TRIGGER
FREQUENCY SWEEP VOLTAGE
SIGNAL WIDTH
POTENTIOMETER
SIGNAL FREQ
FREQUENCY MODULATED R-F OSCILLATOR
D C REFLECTOR VOLTAGE
PHASE
POTENTIOMETER
F-M TEST SIGNAL
POWER SET
VARIABLE R-F ATTENUATOR (UNCALIBRATED)
POWER SUPPLY
LINE SWITCH
ON-OFF
2 AMP
FUSES
HEATERS
115 V A C
LINE POWER INPUT
VIDEO AMPLIFIER
DETECTED R-F TRIGGER
CRYSTAL
R-F DETECTOR
FUNCTION SELECTOR
TEST
R-F CUT-OFF SWITCH IN WAVE GUIDE (OPERATED BY TEST KNOB)
METER BALANCE
POTENTIOMETER
DIRECT CURRENT TO BRIDGE
R-F TRIGGER PULSE FROM INPUT SIGNAL
F-M TEST SIGNAL
INPUT SIGNAL
RF
INPUT AND OUTPUT
STEP R-F ATTENUATOR 0 AND 40 DBM STEPS (OPERATED BY TEST KNOB)
F-M TEST SIGNAL
INPUT SIGNAL
DBM
CALIBRATED VARIABLE R-F ATTENUATOR +7 TO +30 DBM -40 TO -83 DBM
F-M TEST SIGNAL
INPUT SIGNAL
R-F POWER LEVEL BRIDGE (1.0 MW AT SET POWER)
BRIDGE METER
F-M TEST SIGNAL AND INPUT SIGNAL
FREQUENCY
ABSORPTION FREQUENCY METER 8500 TO 9600 MC
NOTES
1 NAMES ENCLOSED IN BOXES ARE CONTROL PANEL MARKINGS
2 DOTTED LINES DENOTE MECHANICAL LINKAGE
3 HEAVY LINES INDICATE PATHS OF MICROWAVE POWER

Figure 12–5.—Block diagram of test set TS–147/UP.

The output of the test oscillator is controlled directly by means of the POWER SET attenuator and the r-f cutoff. The POWER SET attenuator adjusts the signal level applied to the thermistor bridge. The r-f cutoff is a waveguide switch that can turn the output of the oscillator on or off.

The output level of the test signal is measured by the DBM calibrated attenuator. When the r-f power-level bridge is balanced, the DBM dial directly indicates the test-signal power level in dbms at the r-f receptable.

The frequency of the test signal is measured by the absorption frequency meter. When the frequency-meter cavity is in resonance, part of the test oscillator power is reflected, thereby producing a dip in the bridge meter reading. This resonance also causes a dip in the frequency-response curve when the oscillator is frequency-modulated. The test set can also measure the power and frequency of external r-f signals applied to the test set.

The tests that can be made with this type of test set are described in detail in the test-set handbook of maintenance instructions. In brief, with this test set a radar transmitter may be measured for average power, or may be compared with the rated average power, and its frequency may be checked. Transmitter pulling, AFC tracking, TR recovery time, receiver band pass, frequency, receiver sensitivity, and local-oscillator tuning can all be checked, also. Receivers can be checked for beacon reception. Because of its versatility and because radar components can be bench-checked by it, independently of one another, Radar Test Set TS-147/UP is a valuable test equipment for a ship.

ALIGNMENT: This chapter or book will not deal with alignment of radar or calibration of units of the radar system, as all systems have their own pecularities in calibration and alignment, which may be found in each system's OD's, OP's, and instruction books.

QUIZ

1. Corrective maintenance on radar equipment should start with
   a. a complete check of output signals and voltages.
   b. a complete check of input signals and voltages.
   c. symptom observation and analysis in order to locate the part of the system at fault.
   d. systematic checking of tubes, resistors, and capacitors by visual and other means.
2. Which of the following is the most essential characteristic of an echo box?
   a. Close coupling to the radar antenna.
   b. Cast-bronze cavity.
   c. High Q.
   d. Silvered inner surface.
3. The most useful instrument available with which to check overall radar sensitivity is the
   a. echo box.
   b. power-level meter and signal generator.
   c. standing-wave-ratio meter.
   d. oscilloscope.

4. An echo box may be described as a
   a. crystal detector.
   b. power-level meter.
   c. standing-wave-ratio detector.
   d. resonant cavity.
5. The ringing time of a transmitter depends on the
   a. pulse length and transmitter spectrum.
   b. transmitter-peak power and receiver sensitivity.
   c. coupling losses and echo-box sensitivity.
   d. all of the above.
6. When using an echo box to measure the performance of a radar, it is important to position the antenna so that it points
   a. towards the pick-up dipole when a directional coupler is used.
   b. away from the echo box when a directional coupler is used.
   c. towards the ship's head.
   d. away from masts and nearby targets.
7. In spectrum analysis the frequency distribution of the transmitted pulse is obtained by varying the frequency of the echo box and
   a. plotting echo-box frequency against echo-box output.
   b. retuning the echo box for each increment in transmitter frequency.
   c. viewing the pulse shape on the scope.
   d. viewing the pulse on the echo-box indicator.
8. The frequency-modulated r-f oscillator of the radar test set TS–147/UP is a
   a. traveling-wave oscillator.
   b. two-resonator oscillator.
   c. reflex klystron.
   d. positive-grid oscillator.
9. The sawtooth generator of the TS–147/UP is triggered by a video signal obtained from the
   a. detected r-f pulse from the radar transmitter only.
   b. TRIGGER IN receptacle and the detected r-f pulse simultaneously.
   c. TRIGGER IN receptacle only.
   d. TRIGGER IN receptacle or the detected r-f pulse.
10. An advantage of a radar test set such as the TS–147/UP over an echo box is that the former can be used for testing
   a. transmitter frequency.
   b. overall radar frequency.
   c. transmitter pulling.
   d. independent components of a radar.

True—False

11. Specific schedules of preventive-maintenance operations are listed in each system instruction book.
12. Troubles in radar systems are found by a process of localization, which consists of system troubleshooting and unit troubleshooting.
13. The chief advantage of oscilloscopes and synchroscopes in radar maintenance is that frequency can be measured.
14. Because the resonant cavity of the echo box has a very large high Q and is close coupled to the antenna, its oscillations are not dampened out at once, but continue to "ring" within the cavity.
15. As the first step in the location of a receiver fault, technicians should be trained to make a methodical check of the signal from the input to the output.
16. Ringing time displayed on the range scale is usually spoken of in yard measurements instead of microseconds.
17. The spectrum of a pulse is the frequency distribution of its energy.
18. The double-echo method or target of known range method may be used to calibrate the range indicator zero setting.
19. The frequency meter TS–33/AP is used for measuring frequencies in the X band of the pulsed signals only.
20. Radar test set TS–147/UP cannot be used to check a receiver for beacon response.

CHAPTER 13

MAINTENANCE REPORTS—REPAIR PROCEDURES

Under the present system of organization aboard ship, the basic responsibility for maintenance of any electronic equipment rests with the department that operates the equipment. An officer of the fire-control division has the responsibility for the repair and maintenance of the f-c radar.

It must be remembered, however, that many routine maintenance operations on complicated radar equipment are beyond the capacity of the personnel assigned to operate the radar, and close liaison must be maintained between operating and repair personnel. Equipment logs are a joint responsibility of the operating and repair personnel.

The officer given the responsibility for the f-c radar will be referred to in this chapter as the f-c radar officer so do not confuse him with the ship's electronics officer.

Responsibility of the F-C Radar Officer.—The f-c radar officer needs a thorough technical background to meet his responsibilities. This background is of inestimable value in understanding new types of radar systems, in supervising enlisted personel in his division, and in advising his superior officer in technical matters. Although he himself may not repair any of the radar systems, he should recognize and know how to teach good repair techniques. Operators in constant contact with the equipment should be trained to spot signs of abnormal operation such as unusual sounds, flashes, or odors arising from the equipment; or abnormal sounds from rotating machinery associated with the equipment.

Maintenance publications dealing with the ship's installed radar equipment should be carefully studied. Radar maintenance men should be drilled in the use of these publications to see how quickly they can begin an orderly system of troubleshooting, if trouble starts. These men may be drilled at any time by questioning them on simulated problems and trouble symptoms. The technician should be required to outline the various steps he would take to find the trouble if it existed, and he should be encouraged to refer to all the publications that he would normally use.

Above all, the f-c radar officer must be an administrator and know the status of his equipment. He must require that radar history records be kept for each piece of equipment, must maintain schedules, must space overhaul periods regularly so that the work of his division will be evenly distributed, and must procure technical literature for his technicians. He must arrange for the continual training of his men in radar equipment while at the same time protecting the equipment from excessive manipulation by the technicians.

You, as a technician on board certain ships, may be called upon to share part or all of the aforementioned responsibilities.

MAINTENANCE GUIDANCE

In addition to regular weekly or monthly checks on the sensitivity of the transmitter-receiver, routine physical inspections should be made on the transmitter-receiver, power supplies, antenna, and associated equipment. Lubrication and cleaning schedules recommended by the manufacturer should be followed.

Whenever tubes are replaced in the r-f circuit, the circuit should be retuned, if necessary, to achieve normal sensitivity. New tubes should always be tested before being used.

Exact methods of adjustment and repair are given in detail in instruction books provided with each system. You, as a leading technician, should train your men to proceed methodically in locating faults by first testing those parts that are most accessible and most vulnerable. Previous experience or reference to troubleshooting charts may help to isolate the trouble. If first tests do not disclose the defective component, then voltage checks, point-to-point resistance measurements, or signal-tracing techniques may be necessary.

Reports of trouble from the operator should be routed to the radar officer. Every report should be recorded in the equipment log, and the technician's action should be recorded. The operator who reported the trouble should be told of this action if his interested cooperation is to be maintained. Reports of all routine checks should be made to the radar officer and recorded in equipment logs for future reference.

STANDARD EQUIPMENT INSTRUCTION BOOKS

NavShips specifications require that all instruction books for equipment procured under BuShips contracts conform in outline and pagination. Instruction books of electronic equipment procured by other material bureaus conform to slightly different, though similar, specifications. For equipment procured under BuShips contracts, the instruction books conform to the following plan:

Table of contents.
- I. General description.
- II. Theory of operation.
- III. Installation and initial adjustment.
- IV. Operation.
- V. Operator's maintenance.
- VI. Preventive maintenance.
- VII. Corrective maintenance.
- VIII. Parts lists (sometimes bound in a separate volume).

The equipment instruction book, carefully written by the manufacturer to meet the aforementioned specifications, is an important part of every equipment contract.

You should study carefully the instructions regarding safety and the destruction of abandoned material in combat zones and discuss the instructions with your men so that they may act independently if capture by enemy should appear imminent. It will be readily seen that instruction books are valuable adjuncts to training and to operation of the equipment. They are effective, however, only when USED by the maintenance personnel.

MAINTENANCE BULLETINS AND CLASSIFIED ELECTRONICS PERIODICALS

Instruction books on any particular equipment are commonly written before field experience has been accumulated. In order to disseminate quickly information about approved changes, about new troubleshooting methods, and about maintenance procedures which have been gleaned from practical experience, a system of classified maintenance bulletins is provided in the *Electronic Installation Bulletin*, the *Radar Maintenance Bulletin*, and the *Sonar Maintenance Bulletin*. Revisions are periodically sent to all holders of these publications to keep them current. Authorized changes for confidential equipment are covered by instruction-book change sheets mailed to ships and stations on the allowance lists.

EQUIPMENT RECORDS

The importance to the technician of accurate and complete equipment histories should be emphasized continually. The more overworked a technician is, the greater is his temptation to slight the chore of making immediate entries as soon as approved equipment changes are effected or repairs made. Yet the overworked technician is the one who can profit most from well-kept records which show every change that his predecessors have made on the equipment.

Accurate and timely reports are necessary to enable the material bureaus to discharge their responsibilities in planning for repair parts, in revising contract modifications to equipment, and in determining the characteristics of new equipment.

ELECTRONIC EQUIPMENT HISTORY CARD

The Electronic Equipment History Card, NavShips 536, is used to record all information concerning failures and all other pertinent information concerning units of electronic equipment. One of these cards should be made out for each unit of the system. It is transferred with the unit, if the unit is removed. The heading of the card should be typed and the body may be typed, or written in ink or indelible pencil. The ordinary type of pencil should not be used.

The following instructions should be closely observed (study figure 13–1 while reading these):

Equipment model designation.—Include all letters and numbers by which the model is designated.

Equipment serial number.—This number is taken from the equipment name plate—not from the unit name plate. If the plate bears no serial number, place an asterisk in this space. If an overall equipment serial number is not available, list the serial number of the major unit for the entire equipment.

Name of unit and type number.—This number is taken from the name plate of the unit.

Card number.—In the space for the card numbering, the number 1 is on all cards in the original set-up. Number the cards consecutively for all additional cards under each unit.

Name of contractor.—Give the name of contractor in full, as on the equipment name plate or in the instruction book.

Contract number.—For this number use the letters and numbers given on the equipment name plate.

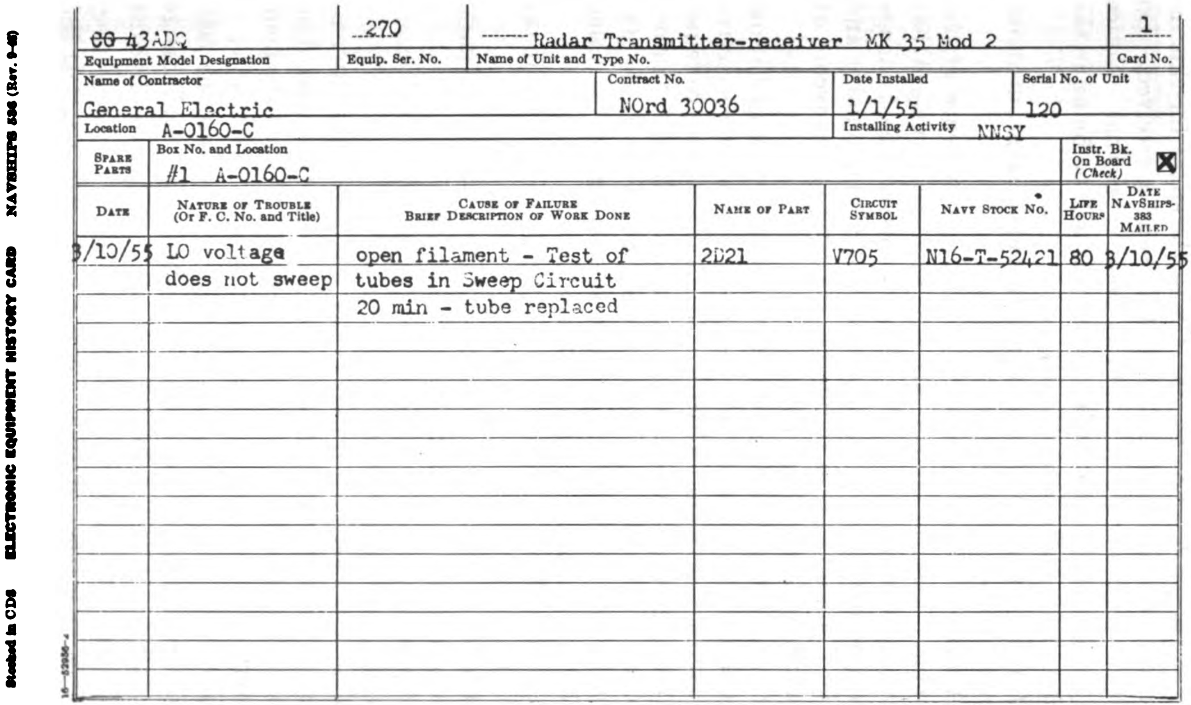
Date installed.—Give the date when installation was completed.

Serial number of unit.—This number is taken from the unit name plate and is not to be confused with the equipment serial number.

Location.—This refers to the location of the unit aboard ship. If the unit is portable, enter the space where it is normally stowed.

Installing activity.—Give the name of the activity that performed the installation.

Box number and location.—Enter the box number and location of all boxes containing repair parts for a particular unit.



Stocked in CDS ELECTRONIC EQUIPMENT HISTORY CARD NAVSHIPS 536 (Rev. 9-48)

Equipment Model Designation: CO-43ADQ

Equip. Ser. No.: 270

Name of Unit and Type No.: Radar Transmitter-receiver MK 35 Mod 2

Card No.: 1

Name of Contractor: General Electric

Contract No.: NOrd 30036

Date Installed: 1/1/55

Serial No. of Unit: 120

Location: A-0160-C

Installing Activity: NNSY

Spare Parts — Box No. and Location: #1 A-0160-C

Instr. Bk. On Board (Check) ☒

Date	Nature of Trouble (Or F. C. No. and Title)	Cause of Failure Brief Description of Work Done	Name of Part	Circuit Symbol	Navy Stock No.	Life Hours	Date NavShips-383 Mailed
3/10/55	LO voltage	open filament - Test of	2D21	V705	N16-T-52421	80	3/10/55
	does not sweep	tubes in Sweep Circuit					
		20 min - tube replaced					

16—52956-4

Figure 13–1.—Electronic Equipment History Card, NAVSHIPS 536.

Instruction book on board.—Check the space for this information when the final instruction book is received. Do not check if only the preliminary book is received. Notice of availability of final instruction books will be found in the appropriate maintenance bulletins.

Date.—Enter the date of a failure, field change, or other work involving repair or maintenance.

Nature of trouble.—Enter any external evidence of the trouble. Describe in detail the equipment performance that was symptomatic of trouble. Also, whenever a field change is made that affects a unit, enter a field-change number and title. This entry is in addition to the entry on the record of field changes, NavShips 537.

Cause of trouble.—THIS IS VERY IMPORTANT. Describe how the trouble was traced, time required, and what corrective measures were taken. Give detailed information. Note peculiarities and weaknesses of the unit. The fuller the information in this column, the greater will be its value to the station, to the manufacturer, and to the bureau. This value will be reflected in more reliable equipment.

Name of part.—List the names of the parts involved in the failure.

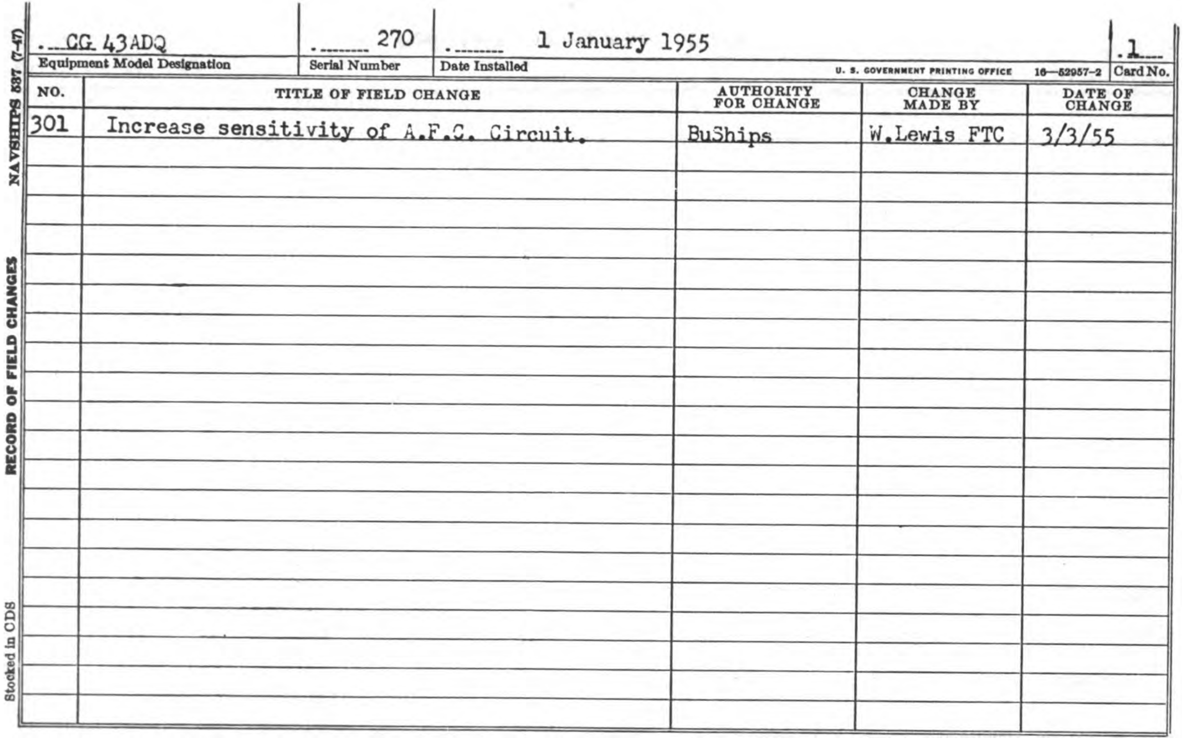
Circuit symbol.—Give the symbol designations of the parts that failed as listed in the instruction book.

Navy stock number.—Include all prefix and suffix letters exactly as given in the instruction book.

Life hours.—ESTIMATE, AS CLOSELY AS POSSIBLE IN HOURS, THE ACTUAL LIFE OF THE PARTS INVOLVED IN THE FAILURE. Use the machinery history cards, the reading of the tube-hour meters, or any other available date to obtain this estimate.

Date that DD 787 was mailed.—Record the date the failure report card was mailed to the bureau. If a field change is made, record also the data the field change report card (NavOrd 1830) was mailed to the bureau.

The importance of filling out the Failure Report DD 787 should be stressed to your men as well as the proper procedure in filling the report. See figure 13–3. One copy of each report should be forwarded to Chief of Bureau of Ships



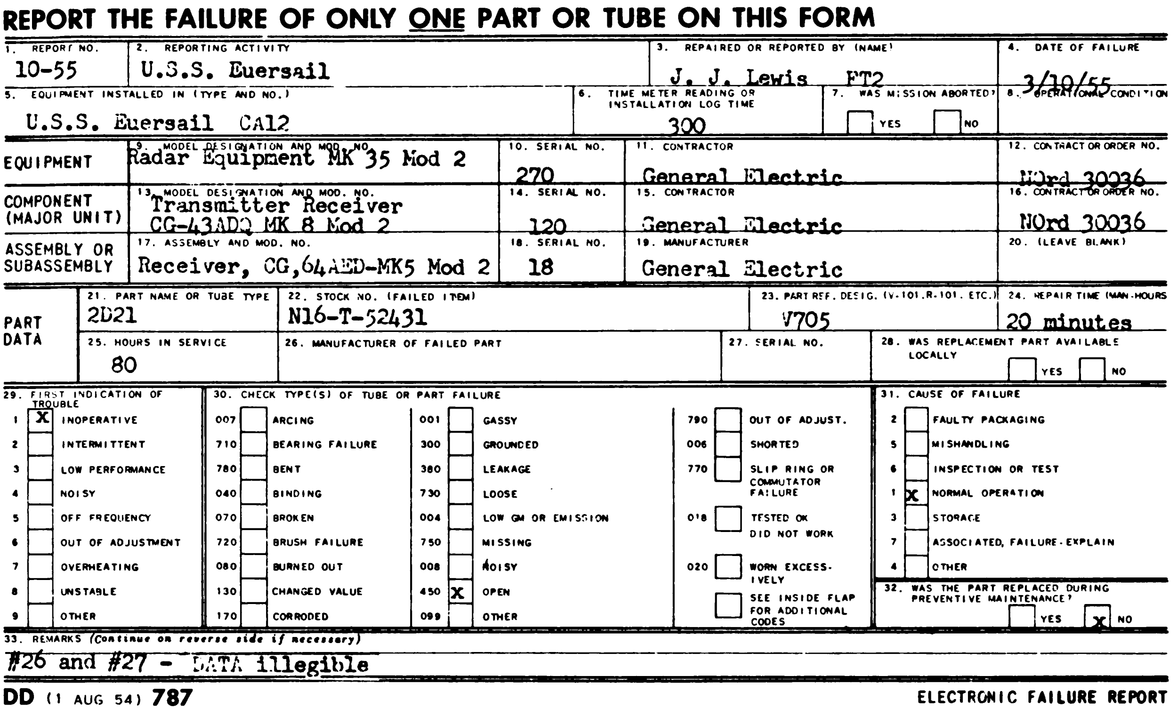
NAVSHIPS 537 (7-47) RECORD OF FIELD CHANGES Stocked in CDS

CG 43ADQ Equipment Model Designation	270 Serial Number	1 January 1955 Date Installed	1 Card No.

U. S. GOVERNMENT PRINTING OFFICE 16—52957-2

NO.	TITLE OF FIELD CHANGE	AUTHORITY FOR CHANGE	CHANGE MADE BY	DATE OF CHANGE
301	Increase sensitivity of A.F.C. Circuit.	BuShips	W.Lewis FTC	3/3/55

Figure 13–2.—Record of Field Changes, NAVSHIPS 537.



REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. REPORT NO. 10-55	2. REPORTING ACTIVITY U.S.S. Euersail	3. REPAIRED OR REPORTED BY (NAME) J. J. Lewis FT2	4. DATE OF FAILURE 3/10/55
5. EQUIPMENT INSTALLED IN (TYPE AND NO.) U.S.S. Euersail CA12	6. TIME METER READING OR INSTALLATION LOG TIME 300	7. WAS MISSION ABORTED? ☐ YES ☐ NO	8. OPERATIONAL CONDITION

EQUIPMENT	9. MODEL DESIGNATION AND MOD. NO. Radar Equipment MK 35 Mod 2	10. SERIAL NO. 270	11. CONTRACTOR General Electric	12. CONTRACT OR ORDER NO. NOrd 30036
COMPONENT (MAJOR UNIT)	13. MODEL DESIGNATION AND MOD. NO. Transmitter Receiver CG-43ADQ MK 8 Mod 2	14. SERIAL NO. 120	15. CONTRACTOR General Electric	16. CONTRACT OR ORDER NO. NOrd 30036
ASSEMBLY OR SUBASSEMBLY	17. ASSEMBLY AND MOD. NO. Receiver, CG,64AED-MK5 Mod 2	18. SERIAL NO. 18	19. MANUFACTURER General Electric	20. (LEAVE BLANK)

PART DATA	21. PART NAME OR TUBE TYPE 2D21	22. STOCK NO. (FAILED ITEM) N16-T-52431	23. PART REF. DESIG. (V-101, R-101, ETC.) V705	24. REPAIR TIME (MAN-HOURS) 20 minutes
	25. HOURS IN SERVICE 80	26. MANUFACTURER OF FAILED PART	27. SERIAL NO.	28. WAS REPLACEMENT PART AVAILABLE LOCALLY ☐ YES ☐ NO

29. FIRST INDICATION OF TROUBLE
- 1 ☒ INOPERATIVE
- 2 ☐ INTERMITTENT
- 3 ☐ LOW PERFORMANCE
- 4 ☐ NOISY
- 5 ☐ OFF FREQUENCY
- 6 ☐ OUT OF ADJUSTMENT
- 7 ☐ OVERHEATING
- 8 ☐ UNSTABLE
- 9 ☐ OTHER

30. CHECK TYPE(S) OF TUBE OR PART FAILURE
- 007 ☐ ARCING
- 710 ☐ BEARING FAILURE
- 780 ☐ BENT
- 040 ☐ BINDING
- 070 ☐ BROKEN
- 720 ☐ BRUSH FAILURE
- 080 ☐ BURNED OUT
- 130 ☐ CHANGED VALUE
- 170 ☐ CORRODED
- 001 ☐ GASSY
- 300 ☐ GROUNDED
- 380 ☐ LEAKAGE
- 730 ☐ LOOSE
- 004 ☐ LOW GM OR EMISSION
- 750 ☐ MISSING
- 008 ☐ NOISY
- 450 ☒ OPEN
- 099 ☐ OTHER
- 790 ☐ OUT OF ADJUST.
- 006 ☐ SHORTED
- 770 ☐ SLIP RING OR COMMUTATOR FAILURE
- 018 ☐ TESTED OK DID NOT WORK
- 020 ☐ WORN EXCESSIVELY
- ☐ SEE INSIDE FLAP FOR ADDITIONAL CODES

31. CAUSE OF FAILURE
- 2 ☐ FAULTY PACKAGING
- 5 ☐ MISHANDLING
- 6 ☐ INSPECTION OR TEST
- 1 ☒ NORMAL OPERATION
- 3 ☐ STORAGE
- 7 ☐ ASSOCIATED, FAILURE-EXPLAIN
- 4 ☐ OTHER

32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? ☐ YES ☒ NO

33. REMARKS (*Continue on reverse side if necessary*)

#26 and #27 - DATA illegible

DD (1 AUG 54) **787**

ELECTRONIC FAILURE REPORT

A15907

Figure 13–3.—Failure Report, DD 787.

within 7 days of the actual failure. All reports of a multiple failure of associated parts should be secured together to permit proper evaluation. Each reporting activity should assign consecutive serial numbers to the reports. These numbers consist of the serial number and the last two digits of the year, as, for example, 1–55, 2–55, 3–55, etc. Items 7 and 8 of the report are not required by Bureau of Ordnance. Items 26 and 27 of the sample form have not been filled in as the data was not legible, but further efforts should be made to obtain this data as it is important.

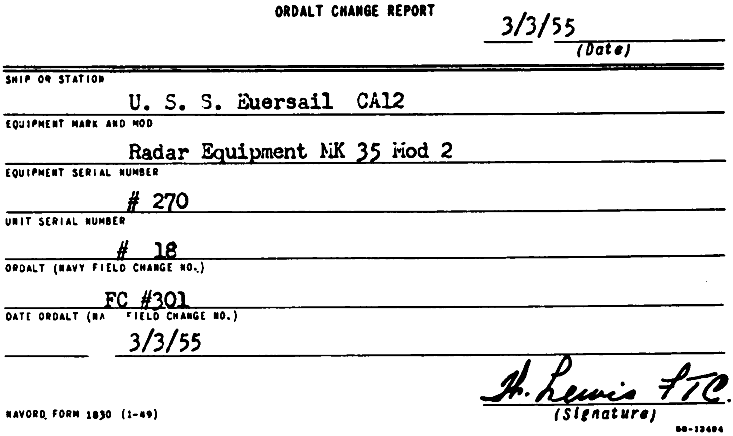
Technicians, ashore and afloat, can be sure that their efforts in filling out the electronics failure reports are put to good use. The technician on the spot of the trouble is in the best position to prepare data to keep the engineers and manufacturers informed as to whether equipment works properly. He is a vital link between the fleet and the bureaus in the feedback of failure data. Bureau engineers have a high regard for the shipboard technician. They know the difficult situation in which the technician often finds himself: he is required to get an equipment working within a certain time; he may or may not have the best training, the test equipment, and the maintenance parts to fix it. But fix it he must—and does.

There are many users of the failure data received from the fleet and shore activities. As has been suggested, bureau maintenance engineers, who need to know how equipment is performing, are among the main users of failure data. In addition to monthly tabulations, they receive a semiannual comprehensive tabulation of totals of failures for each tube and each part of each equipment. Included in this summary, or cross-tabulation, are monthly totals of failures by circuit symbol, an annual total, and a figure for the previous period. This information is used to tell whether or not field changes should be made.

Bureau design engineers receive a monthly tabulation of failures of specific parts as denoted by circuit symbol designations in the various equipment models. Leading contractors are also notified monthly of failures occuring in equipment they have manufactured. Analysis of this information may reveal causes of failure to be either faulty parts or the misapplication of good parts.

FIELD-CHANGE PROGRAM

In electronics the term "field change" means any bureau-authorized mechanical or electrical change, modification, or alternation made to any part of an electronic unit or equipment after delivery to the Navy.



ORDALT CHANGE REPORT

3/3/55 (Date)

SHIP OR STATION: U. S. S. Euersail CA12

EQUIPMENT MARK AND MOD: Radar Equipment MK 35 Mod 2

EQUIPMENT SERIAL NUMBER: # 270

UNIT SERIAL NUMBER: # 18

ORDALT (NAVY FIELD CHANGE NO.): FC #301

DATE ORDALT (NA FIELD CHANGE NO.): 3/3/55

H. Lewis FTC (Signature)

NAVORD FORM 1830 (1-49)

80-13404

Figure 13–4.—Field Change Report Card, NAVORD 1830.

Field changes applicable to electronic equipment under the cognizance of the Bureau of Ordnance may be initiated only by the Bureau of Ordnance. The initiation of these changes may be based on previous recommendations made by naval activities ashore or afloat or by commercial manufacturers.

There are two types of field changes. The first type consists of a kit containing the necessary parts and materials for modifying the equipment, repair parts, two copies of the Field Change Bulletin of Instructions, two copies of instructions for correcting the instruction book, two sets of new and revised pages and associated drawings for the instruction book as applicable, and one Field Change Report Card, NavOrd 1830. The second type of field change consists of only the two bulletins of instructions, the two sets of instruction-book correction pages, and one Field Change Report Card, NavOrd 1830.

The bulletins of instruction consist of descriptive material and details, including a step-by-step procedure for accomplishing the change that is to be made to the equipment.

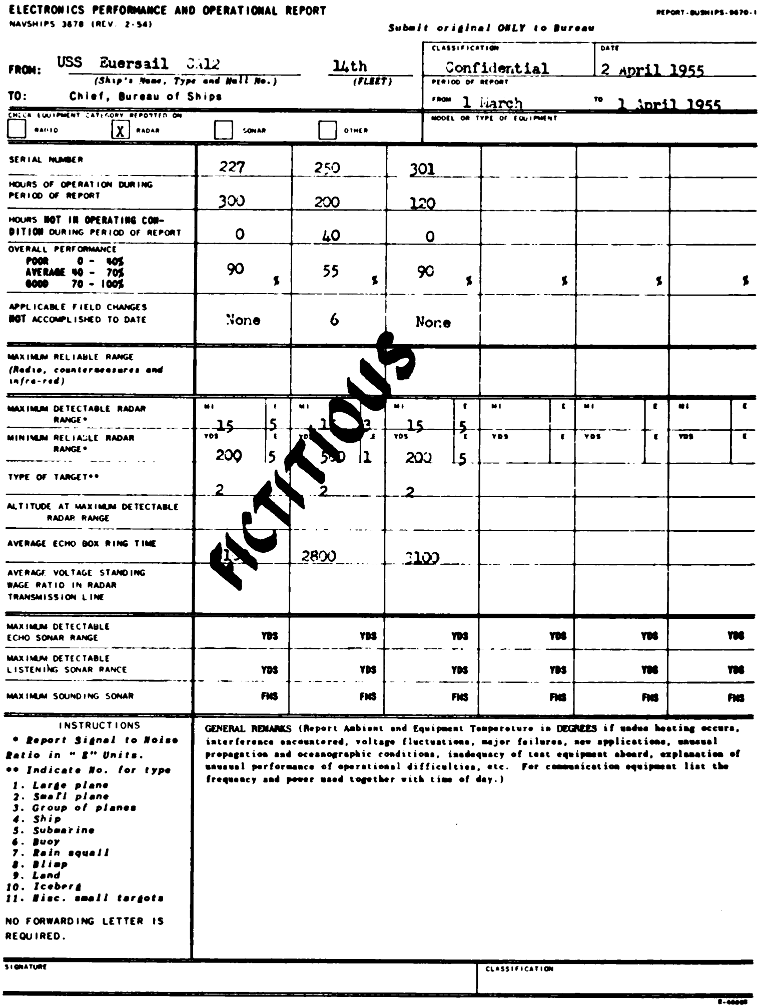
After the equipment has been modified, the instruction book should be corrected in accordance with the instructions included with the kit. The Field Change Report Card, NavOrd 1830, should be filled in and mailed by the personnel making the change. See figure 13–4.

Following this, personnel making the change should record the completion of the change on the equipment History Card, NavShips 536, and the completion data on the Field Change Record Card, NavShips 537.

ELECTRONICS PERFORMANCE AND OPERATIONAL REPORT

The Bureau of Ships requires monthly reports on certain electronic equipment. Those on which reports are required are listed in the electronics maintenance book and submitted by confidential letter. These reports are essential in keeping the Bureau of Ships informed on equipment performance and operation. They are of extreme value because they provide that Bureau with first-hand information on equipment under actual operating conditions and report the maximum ranges obtained by each equipment.

Figure 13–5 shows a prepared Electronics Performance and Operational Report. The importance of the space allowed for general remarks is emphasized. In this space should be indicated any information not included elsewhere on the form, such as detailed information on any unusual trouble encountered in operation, exceptional maintenance required, types of targets tracked at the maximum ranges reported, and suggestions for improvement in design, tests and new applications.



ELECTRONICS PERFORMANCE AND OPERATIONAL REPORT
NAVSHIPS 3878 (REV. 2-54)

REPORT-BUSHIPS-9670-1

Submit original ONLY to Bureau

FROM: USS Euersail CA12 (*Ship's Name, Type and Hull No.*)
14th (*FLEET*)
TO: Chief, Bureau of Ships

CLASSIFICATION: Confidential
DATE: 2 April 1955
PERIOD OF REPORT: FROM 1 March TO 1 April 1955

CHECK EQUIPMENT CATEGORY REPORTED ON: ☐ RADIO ☒ RADAR ☐ SONAR ☐ OTHER

MODEL OR TYPE OF EQUIPMENT

FICTITIOUS

SERIAL NUMBER	227	250	301			
HOURS OF OPERATION DURING PERIOD OF REPORT	300	200	120			
HOURS NOT IN OPERATING CONDITION DURING PERIOD OF REPORT	0	40	0			
OVERALL PERFORMANCE POOR 0 - 40% AVERAGE 40 - 70% GOOD 70 - 100%	90 %	55 %	90 %	%	%	%
APPLICABLE FIELD CHANGES NOT ACCOMPLISHED TO DATE	None	6	None			
MAXIMUM RELIABLE RANGE (*Radio, countermeasures and infra-red*)						
MAXIMUM DETECTABLE RADAR RANGE*	MI 15 E 5	MI 1[illegible] E 3	MI 15 E 5	MI E	MI E	MI E
MINIMUM RELIABLE RADAR RANGE*	YDS 200 E 5	YDS 5[illegible]0 E 1	YDS 200 E 5	YDS E	YDS E	YDS E
TYPE OF TARGET**	2	2	2			
ALTITUDE AT MAXIMUM DETECTABLE RADAR RANGE						
AVERAGE ECHO BOX RING TIME	1[illegible]	2800	3100			
AVERAGE VOLTAGE STANDING WAVE RATIO IN RADAR TRANSMISSION LINE						
MAXIMUM DETECTABLE ECHO SONAR RANGE	YDS	YDS	YDS	YDS	YDS	YDS
MAXIMUM DETECTABLE LISTENING SONAR RANGE	YDS	YDS	YDS	YDS	YDS	YDS
MAXIMUM SOUNDING SONAR	FMS	FMS	FMS	FMS	FMS	FMS

INSTRUCTIONS

* *Report Signal to Noise Ratio in "E" Units.*
** *Indicate No. for type*

1. *Large plane*
2. *Small plane*
3. *Group of planes*
4. *Ship*
5. *Submarine*
6. *Buoy*
7. *Rain squall*
8. *Blimp*
9. *Land*
10. *Iceberg*
11. *Misc. small targets*

NO FORWARDING LETTER IS REQUIRED.

GENERAL REMARKS (Report Ambient and Equipment Temperature in DEGREES if undue heating occurs, interference encountered, voltage fluctuations, major failures, new applications, unusual propagation and oceanographic conditions, inadequacy of test equipment aboard, explanation of unusual performance of operational difficulties, etc. For communication equipment list the frequency and power used together with time of day.)

SIGNATURE

CLASSIFICATION

8-44008

Figure 13–5.—Electronics Performance and Operational Report, NAVSHIPS 3878.

The fact of forwarding suggested improvements is not to be construed, however, as authority to modify the equipment in any way. Nor does the forwarding of this report eliminate the requirement for forwarding the Electronic Failure Report, DD 787, for each failure of electronic equipment.

CURRENT SHIP'S MAINTENANCE PROJECT

The purpose of the Current Ship's Maintenance Project (CSMP) is to provide a current record of maintenance, modifications, and repairs yet to be accomplished by ship's personnel or during availabilities. The CSMP is comprised essentially of the following three cards: Repair Record Card (NavShips 529), which is a blue card; Alteration Record Card (NavShips 530), which is pink; and Record of Field Changes (NavShips 537), which is white. As a repair is required, or an alteration or field change authorized, the applicable card is completed and filed in the material history binder adjacent to the appropriate history card. Being of distinctive colors, the cards readily indicate work yet to be done as the binder is examined.

With the exception of the Record of Field Changes, when work is completed notations to this effect are entered on the Material History Card. Then the applicable CSMP cards are removed from the binder and placed in a "completed work" file.

REPAIR RECORD CARDS and ALTERATION RECORD CARDS are retained for a period of 2 years after the work noted thereon is completed and entries made in the material history. After the 2-year period these cards may be destroyed at the discretion of the commanding officer. When ships are decommissioned or placed out of service during this 2-year period, the cards are retained on board.

SURVEY OR EXCHANGE OF DEFECTIVE EQUIPMENT

When a major unit of equipment is surveyed or exchanged, it is necessary to correct the field change records to show what equipment remains on board. Therefore, the following actions should be taken:

(a) A line should be drawn through all field changes that apply only to the unit being surveyed or exchanged. The field change numbers so canceled should be entered on a supplementary record of field change card.

(b) Where field changes apply only partly to the unit being surveyed or exchanged, the field change number and title should be entered on the supplementary card with a parenthetical note that it applies only to the particular unit.

(c) Replacement units received with equipment history cards should have field change information posted from these cards to the supplementary record of field changes mentioned above. Where no history is available, the unit should be carefully examined and those field changes that have been made should be noted on the supplementary card.

TUBE PERFORMANCE RECORD

The Tube Performance Record, NavShips 538, is for use with service-life-guaranteed tubes and applies only to tubes for which performance is recorded. The column headings are self-explanatory.

All personnel are urged to keep records to the best of their abilities. The records are useful only when properly kept. When kept up to date in accordance with instructions, they provide a valuable reference, they aid in maintenance and repair work, and they improve the quality and dependability of electronic equipment.

OMISSIONS AND INACCURACIES NOTED

The result of omissions and inaccuracies on reports is a waste of effort on the parts of both the technicians and the bureau personnel who process the reports. Failure reports which are not filled out correctly take ten times as much effort and time to process as do those which are complete, accurate, and properly executed. In addition, the users of electronics failure report data are not getting the most accurate summaries. This is particularly true in the case of the category, "life hours" on form DD–787, where omissions are very frequent. As has been stated, a good source of life-hours information, particularly on recurring failures, is the machinery history index where all failures are recorded. In the absence of exact information, technicians should make an estimate of life hours and include it on the report. In any case, the absence of life-hours information should not prevent submission of the report; the other information included is important and useful, too.

QUIZ

1. Maintenance of the electronic equipment is basically the responsibility of the
   - a. electronic repair officer.
   - b. radar repair officer.
   - c. department which is charged with operating it.
   - d. division officer in the engineer department.
2. Equipment logs are the responsibility of
   - a. the repair personnel.
   - b. both the operating and the repair personnel.
   - c. radar or electronic repair officer.
   - d. the operating personnel.
3. The chief advantage of oscilloscopes and synchroscopes in radar maintenance is that
   - a. amplitude can be measured.
   - b. calibrated scales can be seen.
   - c. signal shapes can be seen.
   - d. frequency can be measured.
4. Reports of trouble from an operator on a radar system
   - a. should be routed to the radar officer.
   - b. should be recorded in the equipment log.
   - c. should be reported to the technician for proper action.
   - d. require all of the above actions.
5. Accurate and timely reports are necessary to enable the material bureaus to discharge their responsibilities in
   - a. planning for spares.
   - b. revising contract modification to equipment.
   - c. determining the characteristics of new equipment.
   - d. all of the above.

True—False

6. Faults can often be diagnosed by studying an accurately kept equipment log, as well as troubleshooting charts.
7. Charts of periodically recorded tube currents and circuit voltages provide an effective means of checking transmitter operation.

8. The equipment instruction book, written by the manufacturer, is not considered an important part of the equipment contract.
9. The Electronic Equipment History Card, NavShips 537, should be made out for each unit of the system.
10. Whenever a field change is made that affects a unit, enter the field-change number and title on NavShips 536.
11. All field changes should be recorded on NavOrd 1830, and filed with the Machinery History Cards.
12. A technician is a vital link between the fleet and the bureau in the feedback of failure data.
13. Leading contractors are notified monthly of failures occurring in equipment they have manufactured.
14. A technician may initiate a field change on his equipment to better its performance, and then notify BuOrd.
15. The Tube Performance Record, NavShips 538, is used to record the life performance of all tubes.

CHAPTER 14

SAFETY PRECAUTIONS

The safety of its personnel and the preservation of its material have always been of major concern to the Navy Department. Evidence of this is the fact that all naval activities conduct effective and continuous accident prevention programs. Only those operating procedures and work methods which do not expose personnel unnecessarily to injury or occupational health hazards are approved for adoption.

Instruction in appropriate safety precautions is given by all commands and disciplinary action is taken in case of willful violations. New safety measures, as they are developed, reach all naval establishments by means of instructional directives or manuals.

A comprehensive program of safety engineering, such as that employed by the Navy Department, needs a central and authoritative publication for ready reference which incorporates all information which will be instrumental in avoiding preventable accidents and in maintaining a healthful working environment.

With this end in view, the Office of the Chief of Naval Operations, in collaboration with the technical assistants in the various Bureaus and Offices of the Department, has prepared a compilation of Navy-wide safety instructions under the title *United States Navy Safety Precautions*, OPNAV 34P1. While this publication is not intended as the "last word" in naval safety methods, being loose-leaf in form for easy inclusion of omissions and modifications, it does give comprehensive coverage of most of the hazards involved and the applicable precautions for a given type of work, either afloat or ashore. You should study the chapter applicable for your work.

The f-c radar officer is charged with the safety and well-being of all enlisted men on the radar maintenance force under his direction. At the same time, he is directly responsible for the proper functioning of the radar systems.

Attitudes of men toward safety are important. In their concern for optimum functioning of gear, many young technicians neglect the safety warnings found in instruction books that accompany every piece of equipment. To impress upon all hands that their first duty is to keep themselves, as well as their equipment, in fighting trim is an important responsibility of the radar officer, and of LEADING PETTY OFFICERS.

Although every ship and shore station has its peculiar safety applications, the following general precautions, quoted from the *Bureau of Ships Manual*, part 14, chapter 67, should be noted:

> *General.*—Safety precautions as herein listed shall not be considered to supersede specific precautionary measures applicable to a particular equipment.

Work done by authorized persons.—Because of the danger of fire, damage to material, and personnel injury, all repair and maintenance work on electronic equipment shall be done by duly authorized and assigned persons only.

Tagging open switches.—When any electronic equipment is to be overhauled or worked on, the main supply switches or cut-out switches in each circuit from which power could possibly be fed shall be secured in the open position and tagged. The tag shall read "This circuit was ordered open for repairs and shall not be closed except by direct order of ---------" (usually the person making, or directly in charge of the repairs). After the work has been completed, the tag or tags shall be removed by the same person.

Operating switches.—As a general rule, use only one hand for switching. Keep the other hand clear. One switch only should be touched at one time by one person. Before closing a switch, make sure that:

1. The provisions of the preceding article have been complied with, where practicable.
2. The circuit is ready and all parts are free.
3. Men near moving parts are notified that the circuit is to be energized.
4. Proper fuses are installed for protection of the circuit.
5. Circuit breaker is closed.

Ease the switch to a position of safe and quick action and then make the final motion positive and rapid. When opening switches carrying current, the break should be positive and rapid.

Fuses.—Fuses should be removed and replaced only after the circuit has been completely deenergized. When a fuse blows, it shall be replaced with a fuse of the same rated ampere capacity. When practicable, a circuit should be checked before replacing a burned-out fuse, as such trouble is usually indicative of a circuit fault.

Circuit breakers.—Except for operating handles, all parts of circuit breakers are normally conductors. In opening and closing breakers:

1. Use only one hand.
2. Keep the hands clear of parts other than operating handles.
3. Touch only one breaker handle at a time.
4. Where positive and negative breakers have two handles, they shall not be closed at one time.
5. Close the breaker and then the switch.
6. Trip circuit breakers before opening switches.
7. Keep the face turned away while closing circuit breakers.
8. Never disable a circuit breaker.
9. Never stand over a circuit breaker while power is on.

Energized circuits.—Insofar as practicable, repair work on energized circuits shall NOT be undertaken. When repair work of an emergency nature or repair work considered essential is undertaken, on an energized circuit, it shall be accomplished under supervision of an experienced technician or radar officer. In all such work, every care shall be taken to insulate from ground the person performing the work and to use every known safety precaution. The following precautions shall be taken where practicable:

1. Provide ample light for illumination.
2. Remove loose clothing.
3. Insulate worker from ground with dry wood, several layers of dry canvas, or a sheet of phenolic insulating material or sandpaper.
4. Cover working metal tools with insulating rubber tape (not friction tape) as far as practicable.
5. Use only one hand, if practicable, in accomplishing the work.
6. A rubber glove should be used on the hand not used for handling tools and, if the nature of the work permits, rubber gloves should be worn on both hands.
7. Have men stationed by circuit breakers or switches so that the circuit or switchboard can be deenergized immediately in case of emergency.
8. A man qualified in first aid for electric shock shall stand by during the entire period of repairs.

Cleaning switchboards, etc.—Cleaning of switchboards, panels, boxes, etc., shall be limited to removing loose dirt with a painter's duster having no metallic part and made of soft bristles about 4 inches long.

Alcohol.—Alcohol shall not be used on energized equipment or on equipment near other electronic equipment from which a spark is possible. Alcohol shall be exposed in the smallest possible quantity. Alcohol shall be used only in well ventilated compartments. Except in locations wholly in the open, alcohol shall be limited in quantity to 1 pint.

Volatile liquids.—When working with volatile liquids, such as insulating varnish, paint, lacquer, turpentine, kerosene, etc., ample ventilation shall be provided to prevent accumulation of inflammable vapors.

Electrical fires.—In case of electrical fire:

1. Deenergize the circuit.
2. Secure ventilation.
3. Extinguish the fire.

4. Report casualty to the O. O. D. by messenger or telephone.

When extinguishing an electrical fire, remember that quick action is required only to deenergize the circuit. When this has been done, STOP, LOOK, THINK. The use of a CO_2 (carbon-dioxide) fire extinguisher directed at the base of the flame is always best for all electrical fires.

Pyrene or carbon tetrachloride is excellent for extinguishing an electrical fire, but when it contacts hot metal, it changes to phosgene (a poison gas), which even in the open air creates a hazardous condition. Pyrene or carbon tetrachloride, therefore, shall never be used for fires of electrical origin.

In case of cable fires in which the inner layer of insulation, or insulation covered by armor, supports combustion, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the two ends.

Loose metal parts.—No person shall take loose metal parts or liquid near or above open electronic equipment. No person shall go above open electronic equipment without first removing all metal from his pockets. Stowage or insertion of foreign articles in or near switch-gear control appliances, panels, etc., is forbidden.

Fuse boxes, etc., to be kept closed.—All fuse boxes, junction boxes, lever-type boxes, and wiring accessories shall be kept closed.

Portable cable.—Portable cable shall be carefully selected and shall be of proper length and cross-sectional area. Spliced portable cables are extremely dangerous and shall not be used.

Discharge capacitors.—Prior to touching a capacitor which is connected to a deenergized circuit, or which is disconnected entirely, short-circuit the terminals.

Resuscitation (artificial respiration).—Quick correct artificial respiration can mean the difference between life or death for a man overcome by electric shock. In this regard see chapter 18—Electricity and Electronics, *United States*

Navy Safety Precautions, OpNav 34P1, paragraph 18101 (5) in the original edition; and chapter 67—Electronics, *BuShips Manual*. paragraphs 67–284 and 67–285 in Change No. 10 of that *Manual*. The methods for applying artificial respiration are given in the *Standard First Aid Training Course*, NavPers 10081.

Cleaning electronic equipment.—All electronic equipment shall be cleaned to assure good performance and not for appearance only.

Steel wool or emery in any form shall not be used on or near electronic equipment.

Sandpaper and files shall be used only with competent advice or not at all. Two factors render filings, dust, steel-wool particles, etc., a menace:

1. Ventilating currents distribute them where they may do the greatest harm, and
2. Magnetic poles, often present in electronic equipment, collect ferrous particles.

Interlocks, etc.—Safety devices, such as interlocks, overload relays, and fuses, shall not be altered or disconnected nor safeguard circuits modified without specific authority of the Bureau of Ordnance or Bureau of Ships. Periodic tests and inspections shall be made to insure that they are functioning properly.

Precautions for handling cathode-ray tubes.—Wear goggles to protect the eyes from flying glass particles in event of envelope fracture, which might cause implosion due to high vacuum within the tube. Goggles which provide side and front protection and have clear lenses which will withstand a fairly rigid test are prescribed.

Remove tube from packing box with caution, taking care not to strike or scratch the envelope. Insert into the equipment socket cautiously, using only moderate pressure. Do not jiggle the tube. These precautions also apply when removing the tube from the equipment socket.

Additional safety precautions.—Instructions concerning safety precautions in connection with the installation, maintenance, and operation of the equipment are incorporated in instruction books. These, together with instructions incorporated in this chapter, comprise a nucleus for the promulgation of detailed instructions for safe installation, maintenance, and operation of electronic facilities ashore and afloat. Responsible officers will issue such additional orders and instructions as are deemed necessary for the protection of personnel.

When special situations arise to justify the risk, commanding officers are authorized to modify the above safety precautions to meet the special situation at hand.

QUIZ

1. The best method of extinguishing an electrical fire is to
   a. spray it with salt water.
   b. use a carbon-dioxide fire extinguisher.
   c. smother it with foam.
   d. spray it with pyrene.

2. Which of the following liquids is dangerously volatile?
   a. Lacquer.
   b. Turpentine.
   c. Alcohol.
   d. All of the above.

3. The safety regulations set forth by ***Bureau of Ships Manual*** may be modified by
   a. the electronic or radar repair officer.
   b. the field-service engineers.
   c. commanding officer in special situations.
   d. authorization of the Bureau of Ships only.

4. When replacing a blown fuse in a circuit.
   a. the circuit should be de-energized.
   b. replace it with one of a higher ampere rating.
   c. replace it with one of a higher wattage rating.
   d. the circuit should remain energized for quicker performance.

5. When handling, removing, or replacing cathode-ray tubes,
   a. no precautions are necessary.
   b. handle as an ordinary vacuum tube.
   c. the technician should wear goggles which provide side and front protection and have clear lenses.
   d. the only precaution necessary is in the jiggle of the tube.

True—False

6. The general precautions for safety quoted from the *Bureau of Ships Manual* are intended to supplement rather than supersede specific safety measures in a given situation.

7. When a switch has been tagged in the open position, the tag may be removed by either the originator or by personnel outranking him.

8. All switches should be open before a circuit breaker is tripped.

9. Repair work considered essential may be undertaken on energized circuits if all practicable precautions are observed.

10. A painter's duster with no metal parts may be used for cleaning deenergized switchboards and panels.

11. All electronic equipment should be cleaned with steel wool or emery periodically to assure good performance.

12. It is mandatory that the circuits and capacitors in deenergized equipment be discharged and grounded before repair work is begun.

13. Before safety devices are altered or safeguard circuits modified, authorization must be received from the bureau concerned.

14. It is considered acceptable to replace a fuse without de-energizing a circuit provided the replacement has the same ampere rating and is in an insulated holder.

15. Safety precautions need not be observed with receivers and test equipment operating from a-c lines since the voltage involved is low.

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

TRANSMISSION LINES

1. b
2. d
3. a
4. d
5. c
6. d
7. b
8. d
9. d
10. a
11. True
12. True
13. False
14. True
15. True

CHAPTER 2

WAVEGUIDES AND CAVITY RESONATORS

1. d
2. b
3. a
4. c
5. d
6. d
7. d
8. b
9. a
10. d
11. True
12. True
13. False
14. True
15. True

CHAPTER 3

MICROWAVE COMPONENTS

1. c
2. c
3. c
4. a
5. a
6. c
7. b
8. b
9. a
10. d
11. d
12. False
13. False
14. True
15. True

CHAPTER 4

ANTENNAS

1. c
2. b
3. b
4. False
5. True
6. False
7. True
8. True
9. True
10. True

CHAPTER 5

TRANSMITTERS

1. d
2. d
3. c
4. True
5. False
6. True
7. True
8. True
9. True
10. False
11. False
12. True
13. True
14. False
15. False

CHAPTER 6

RECEIVERS

1. c
2. a
3. a
4. b
5. a
6. a
7. b
8. c
9. a
10. b
11. d
12. b
13. b
14. c
15. d
16. True
17. False
18. True
19. True
20. False

CHAPTER 7

RADAR TIMERS

1. d
2. d
3. c
4. d
5. a
6. b
7. True
8. True
9. True
10. True
11. False
12. False
13. True
14. False
15. True

CHAPTER 8

RADAR RANGE DATA

1. b
2. b
3. a
4. d
5. b
6. True
7. False
8. True
9. True
10. True
11. False
12. False
13. False
14. True
15. True
16. True
17. True
18. False
19. True
20. True

CHAPTER 9

ANTENNA-POSITIONING SYSTEM

1. d
2. c
3. d
4. a
5. b
6. c
7. c
8. a
9. c
10. c
11. False
12. False
13. True
14. False
15. True
16. False
17. True
18. False
19. False
20. True

CHAPTER 10

RADAR AUXILIARY CIRCUITS

1. b
2. d
3. b
4. c
5. True
6. False
7. True
8. False
9. True
10. True

CHAPTER 11

RADAR BEACONS

1. b
2. c
3. a
4. b
5. b
6. c
7. True
8. True
9. True
10. True

CHAPTER 12

RADAR MAINTENANCE AND TEST EQUIPMENT

1. c
2. c
3. a
4. d
5. d
6. d
7. a
8. c
9. d
10. d
11. True
12. True
13. False
14. False
15. False
16. True
17. True
18. True
19. False
20. False

CHAPTER 13

MAINTENANCE REPORTS—REPAIR PROCEDURES

1. c
2. b
3. c
4. d
5. d
6. True
7. True
8. False
9. False
10. False
11. False
12. True
13. True
14. False
15. False

CHAPTER 14

SAFETY PRECAUTIONS

1. b
2. d
3. c
4. a
5. c
6. True
7. False
8. False
9. True
10. True
11. False
12. True
13. True
14. False
15. False

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

FIRE CONTROL TECHNICIANS

RATING CODE NO. 0800

General Service Rating

Scope

Fire control technicians maintain and repair fire control systems, including fire control radars and target designation equipment; make detailed mechanical, electrical, and electronic casualty analyses; test, operate, clean, lubricate, inspect, adjust, and calibrate fire control units; remove, repair, replace, and install or reassemble fire control components and systems; make transmission, computing, and rate tests on fire control systems; boresight guns and align guns or launchers and fire control systems.

Emergency Service Ratings

FIRE CONTROL TECHNICIANS A (Automatic Directors) Rating Code No. 0804 **FTA**
Maintain and repair fire control systems Mk 37, Mk 56, Mk 68, Mk 69, Gunars, surface fire control systems for calibre 6'' and above, and associated equipment.

FIRE CONTROL TECHNICIANS M (Manually Controlled Directors) Rating Code No. 0802 **FTM**
Maintain and repair fire control systems Mk 52, Mk 57, Mk 63, Mk 70 and Mark 51 director, and associated equipment.

FIRE CONTROL TECHNICIANS U (Underwater) Rating Code No. 0803 **FTU**
Maintain and repair fire control systems Mk 101, Mk 102, Mk 104, Mk 105, and Mk 106 or individual components thereof, and associated equipment.

FIRE CONTROL TECHNICIANS G (Missile Guidance Systems) Rating Code No. 0801 **FTG**
Maintain and repair guided missile fire control systems and associated equipment.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classification, NavPers 15105 (Revised), codes FT-1100 to FT-1199.

Ch. No. 4

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
100 PRACTICAL FACTORS					
101 OPERATIONAL					
1. Demonstrate, under simulated conditions, the rescue of a person in contact with an energized electrical circuit; resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
2. Read dials and set operating controls to predetermined values on fire control equipment	3	3	3	3	3
3. Demonstrate on fire control equipment to which assigned, operating procedures and techniques as required to:					
a. Perform operator's adjustments	3	3	3	3	3
b. Perform transmission, computing and rate tests, and report and record results	3	3	3	3	3
4. Demonstrate on target designation equipment of own ship, operating procedures and techniques required to:					
a. Perform operator's adjustments	3	3	3		3
b. Test and interpret qualitative performance of designate and repeatback channels	2	2	2		2
5. Compute corrections to compensate for operator and rangefinder errors	1	1			
6. Demonstrate operating procedures and techniques on fire control equipment to which assigned, as required to train battle station and watch standing operators	C	C	C	C	C
7. Demonstrate operating procedures and techniques on target designation equipment of own ship as required to train battle station and watch standing operators	C	C	C		C

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
101 OPERATIONAL—Continued					
8. Compute ballistics using standard forms and work sheets	C	C	C		
102 MAINTENANCE AND/OR REPAIR					
1. Identify electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment	3	3	3	3	3
2. Identify capacitors and resistors by RMA color codes	3	3	3	3	3
3. Lubricate fire control equipment in accordance with lubrication charts	3	3	3	3	3
4. Make tests of electrical fire control circuits for continuity, grounds and short circuits	3	3	3	3	3
5. Inspect and clean commutator and slip ring assemblies and replace brushes	3	3	3	3	3
6. Make prescribed electronic tests of servo and computing circuits using multimeters, tube testers and cathode ray oscilloscopes and report results	3	3	3	3	3
7. Make operator's adjustments and checks to fire control radars	3	3	3		3
8. Conduct shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3		
9. Trace circuits through fire control and sound powered telephone switchboards and make repairs as necessary	2	2	2	2	2
10. Perform all tests and adjustments necessary for proper operation of servo and computing circuits. Test synchros, interconnecting circuits and switchboards and set synchros to electrical zero	2	2	2	2	2

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR—Con.					
11. Prepare a gun, launcher, director station or target designation system for battery alignment (afloat) by aligning synchros and setting mechanical dials to reference points	2	2	2		2
12. Make internal adjustments and calibrations to fire control radars	2	2	2		2
13. Make standard electronic tests of radar circuits using signal generators, multimeters, tube testers and cathode ray oscilloscopes and report results	2	2	2		2
14. Perform all shipboard maintenance on range-finders not requiring the services of an Opticalman	2	2			
15. Prepare underwater fire control systems for battery alignment (afloat) by aligning synchros and setting mechanical dials to reference points				2	
16. Trace circuits and test synchros and servo-mechanisms and make replacements, adjustments and repairs	1	1	1	1	1
17. Test, remove, replace, and adjust mechanical parts of fire control and/or torpedo control equipment	1	1	1	1	1
18. Analyze failures and make repairs to servo and computing circuits	1	1	1	1	1
19. Lubricate and perform shipboard adjustments to gyroscopes used in fire control equipment	1	1	1	1	1
20. Conduct battery alignment tests and evaluate results	1	1	1		1
21. Boresight guns and align guns or launchers; directors, fire control radar antennas, torpedo fire control directors and indicators on tube mount, and target designation equipment. Test firing cut-out devices for proper operation	1	1	1		1

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
102 MAINTENANCE AND/OR REPAIR—Con.					
22. Perform all tests and adjustments necessary for proper operation of radar circuits	1	1	1		1
23. Align underwater fire control systems. Test firing and firing cut-out devices for proper operation				1	
24. Analyze results of transmission, alignment, computer, and rate tests to determine need for adjustment, replacement of parts or repairs	C	C	C	C	C
25. Conduct all electrical tests on a complete fire control system	C	C	C	C	C
26. Analyze failures and effect repairs to the target designation equipment	C	C	C		C
27. Conduct battery alignment and compute and apply corrections	C	C	C		C
28. Analyze failures and effect repairs to fire control systems	C	C	C	C	C
29. Analyze results of dummy director and error recorder tests and effect necessary repairs and adjustments	C	C	C		C
30. Conduct underwater fire control alignment and compute and apply corrections				C	
103 ADMINISTRATIVE AND/OR CLERICAL					
1. Keep rough logs of periodic tests and maintenance	3	3	3	3	3
2. Make failure reports and keep ordnance histories	2	2	2	2	2
3. Use Ordnance Stock Catalogue	2	2	2	2	2
4. Maintain a Current Ship's Maintenance Project (CSMP) and prepare naval shipyard and tender work request or job order	C	C	C	C	C
5. Maintain supplies and spare parts and obtain replacements	C	C	C	C	C

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	**FTA**	**FTM**	**FTU**	**FTG**
200 EXAMINATION SUBJECTS					
201 OPERATIONAL					
1. Interpret and interpolate a dial setting into minutes, degrees, yards or mils	3	3	3	3	3
2. Effects of electrical shock; method of resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3	3	3	3	3
3. Given course and speed of own ship and target, solve analytically for range rate and linear deflection (bearing) rate	2	2	2	2	2
4. Given course and speed of own ship, and course, speed, and elevation of air target, solve analytically for range rate, linear deflection (bearing) rate, and linear elevation rate	1	1	1		1
5. Operating principles of stereo rangefinders. Methods used to measure operator and rangefinder errors and methods used to compute corrections	1	1			
6. Variables and constants of initial ballistics	C	C	C		
7. Elements of the air and surface fire control problems	C	C	C		C
8. Variables and constants of underwater ballistics	C			C	
9. Elements of underwater fire control problems	C			C	
202 MAINTENANCE AND/OR REPAIR					
1. Types of information shown and meanings of electrical, electronic, and mechanical symbols used in schematic diagrams of fire control equipment excluding fire control quantities	3	3	3	3	3
2. RMA color coding systems for capacitors and resistors	3	3	3	3	3

	Qualifications for Advancement in Rating	*Applicable Rates*				
		FT	FTA	FTM	FTU	FTG
202	MAINTENANCE AND/OR REPAIR—Con.					
	3. Precautions to be observed in lubricating fire control equipment	3	3	3	3	3
	4. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3	3	3	3	3
	5. Methods of testing resistors, potentiometers, coils, transformers, capacitors, and electron tubes and the application of each in voltage amplifier, phase inverter, power supply, oscillator, power amplifier and rectifier circuits. Recognize electronic stages, power supply circuits, and coupling circuits	3	3	3	3	3
	6. Function of each of the elements in gas filled, vacuum, and cathode ray tubes	3	3	3	3	3
	7. Calculate current, voltage, phase angle, impedance, and resistance in series and parallel circuits containing not more than a combination of four elements	3	3	3	3	3
	8. Purposes of the following fire control radar operator's adjustments and checks: Intensity, sweep, focus, centering, receiver gain, receiver tuning, video gain, modulator frequency, range slew, range and train, and elevation zero checks	3	3	3		3
	9. Properties of free and restrained gyroscopes and purpose of damping	3	3	3		3
	10. Purpose and interpretation of shipboard tests of gyro-controlled computing mechanisms, such as lead computing sights and other restrained gyros used in computing angular rate lead angles	3	3	3		
	11. Purposes of transmission, computing, and rate tests	3	3	3	3	3

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	**FTA**	**FTM**	**FTU**	**FTG**
202 MAINTENANCE AND/OR REPAIR—Con.					
12. Types, operating principles, and application of switching gear used in fire control and sound powered telephone switchboards	2	2	2	2	2
13. Characteristics and use of synchros methods of setting to electrical zero	2	2	2	2	2
14. Operating principles (excluding knowledge required *only* in research, engineering and manufacture) of the following: Tuned coupling circuits, impedance matching, cathode followers, modulators and demodulators, oscillators, phase shifters, mixers, heterodyning, automatic gain control, frequency modulation, discriminators, automatic frequency control, integration and differentiation, counting circuits, saw tooth generators, multivibrators, limiters, peakers, clampers, and half and quarter wave antennas	2	2	2	2	2
15. Methods of making gain, phase, balancing, bias and zeroing adjustments of servo loops found in computing and power drive circuits	2	2	2	2	2
16. Use of tram bar, method of setting synchros to electrical zero and method of positioning shafts by adjustable couplings	2	2	2	2	2
17. Types, application, and operating principles of electromechanical servomechanisms	1	1	1	1	1
18. Purpose, operating principles, and adjustments of basic fire control mechanisms	1	1	1	1	1
19. Operating principles of computing circuits, servo loops, and power drive circuits	1	1	1	1	1

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	**FTA**	**FTM**	**FTU**	**FTG**
202 MAINTENANCE AND/OR REPAIR—Con.					
20. Method of mounting and aligning a boresight telescope on a gun or launcher. Purpose and method of aligning sights to gun bore. Purpose and method of checking a director to a reference plane and reference point. Quantities set on inclination compensators. Methods to conduct train and elevation checks (afloat)	1	1	1		1
21. Purpose and operating principles of the following radar circuits: Transmitter, video amplifier, modulation generator, range unit, indicator unit, echo box, dummy antenna, power supply, waveguides, atennas, voltage regulator, transmission lines, IF amplifier, RF amplifier or preselector	1	1	1		1
22. Method of setting up and purpose of dummy director and error recorder tests; information obtained and interpretation of results	1	1	1		1
23. Method of aligning underwater fire control systems	C			1	
24. Purpose and method of the following radar checks: Double echo, receiver sensitivity, standing wave ratio and transmitted power level	C	C	C		C
25. Methods used in battery alignment (afloat and drydock). Use of gunner's quadrant. Method and purpose of static alignment. Principles involved in establishing bench mark and tram points. Method of computation of roller path inclination from horizon checks. Methods of train and elevation checks (afloat)	C	C	C		C

Qualifications for Advancement in Rating	*Applicable Rates*				
	FT	FTA	FTM	FTU	FTG
202 MAINTENANCE AND/OR REPAIR—Con.					
26. Relationship of electrical and mechanical inputs and outputs of a radar, rangefinder, director, computer, stable element, and gun mount of a dual purpose battery	C	C	C		
27. Relationship of electrical and mechanical inputs and outputs of a launcher and missile fire control system	C				C
203 ADMINISTRATIVE AND/OR CLERICAL					
1. Types, purpose of, and entries made in rough logs	3	3	3	3	3
2. Purposes and types of entries made in failure reports and ordnance histories	2	2	2	2	2
3. Types of information found in the following publications: Ordnance Pamphlets, Ordnance Data, Ordnance Circular Letters, Ordnance Handling Instructions, Ordnance Modification Instructions, Ordnance Material Letters, Ordnance Alterations, NavOrd Instructions, and NavOrd Notices	2	2	2	2	2
4. Purpose and scope of the BuOrd Manual as stated in Chapter I	1	1	1	1	1
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